AD 6956803

AUTHORITY: AFWAL

1 14 MAY 85



THIS REPORT HAS BEEN DELIMITED

AND CLEARED FOR PUBLIC RELEASE

UNDER DOD DIRECTIVE 5200.20 AND

NO RESTRICTIONS ARE IMPOSED UPON

ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

FZM-5494 1 April 1970

AD-B956 803

Contract No. F33615-69-C-1494



POINT STRESS LAMINATE ANALYSIS

Dr. D. L. Reed

TE FILE COPY

Advanced Composites Division Air Force Materials Laboratory Wright-Patterson Air Force Base, Ohio



GENERAL DYNAMICS

Fort Worth Division

 $84 \quad 8 \quad 03 \quad 003$

Further Dissemination only as directed by

AFWAL (61/57 technical Industrial 1970)

Or higher DoD Authority.

FZM-5494

1 April 1970

POINT STRESS

LAMINATE ANALYSIS

Prepared by

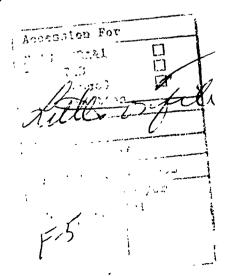
Dr. D. L. Reed

Prepared for

Advanced Composites Division Air Force Materials Laboratory Air Force Systems Command Wright-Patterson Air Force Base, Ohio



GENERAL DYNAMICS
Fort Worth Division



ABSTRACT

This report presents a point stress analysis of a laminate under inplane loads, moments, and temperature effects. The formulation presents the usual lamination theory whereby the laminate constitutive relation is derived from the constitutive relation for each layer in the laminate. Once the laminate relation has been formulated, it is used to determine midplane strains and curvatures which arise due to inplane stress and moment resultants. The midplane strains and curvatures are then used to determine the strains and thus the stresses in each layer of the laminate. The thermal analysis assumes a constant temperature through the thickness. Inplane stress and moment resultants caused by the temperature are calculated and added to the other known loads.

A simplified transverse shear analysis is presented.] This analysis will predict the shear stress distribution across the laminate thickness from known values of the shear resultants $Q_{\mathbf{x}}$ and $Q_{\mathbf{y}}$.

The background necessary to compute a laminate interaction diagram is presented. A laminate interaction diagram depicts allowable average stresses ($\bar{\sigma}_x$, $\bar{\sigma}_y$, and $\bar{\tau}_{xy}$) for a particular laminate based upon the maximum strain theory of failure.

The analyses which are presented have been programmed in Fortran IV as procedure SQ5. This procedure is described in the

Appendix and a sample problem is presented. Some results obtained from using the procedure are also presented. An original laminate analysis program, U65, was revised and modified in writing procedure SQ5.

iii

TABLE OF CONTENTS

Section	<u>Title</u>	Page
I	INTRODUCTION	1
II	FORMULATION OF LAMINATE CONSTITUTIVE EQUATIONS	3
	2.1 Lamina Constitutive Equation	3
	2.2 Strain-Displacement Equations	5
	2.3 Laminate Constitutive Equations	7
III	CALCULATION OF LAMINA STRESSES AND STRAINS FOR AVERAGE INPLANE STRESSES	12
IV	INTERACTION DIAGRAMS	14
v	COMPLETE POINT STRESS ANALYSIS	17
VI	THERMALLY INDUCED STRESSES	19
VII	INTERLAMINAR SHEAR STRESSES	21
VIII	ANALYTICAL RESULTS	24
	8.1 Interaction Diagram	24
	8.2 Bending Analysis	24
	8.3 Interlaminar Shear	25
	8.4 Thermal Expansion Analysis	25
IX	SUMMARY	26
APPENDICES		
I	Description of Computer Program SQ5	27
II	Input Data Description	32
III	Program Listing	41

TABLE OF CONTENTS (Continued)

Section	• •	<u> Title</u>	Page
APPENDICE	SS		
IV	Sample Problem In	put	67
v	Sample Problem Ou	tput	69
REFERENCE	2S		87

LIST OF ILLUSTRATIONS

Figure	<u>Title</u>	Page
1	Lamina and Laminate Axis System	4
2	Stress and Moment Resultants	8
3	Lamina Notation	10
4	Laminate Interaction Diagram	16
5	SO5 Flow Diagram	40

NOMENCLATURE

A	inplane stiffness coefficients
В	coupling coefficients between inplane and bending resultants
	bending stiffness coefficients
A', B', C', D'	submatrices of the inverted laminate constitutive relation
E ₁₁	modulus of elasticity in lamina fiber direction
E ₂₂	modulus of elasticity normal to lamina fiber direction
G ₁₂	shear modulus of elasticity
h _k	coordinate from midplane to kth layer
N	inplane stress resultants
[M]	moment resultants
N^T	thermally induced inplane stress resultants
$M^{\mathbf{T}}$	thermally induced moment resultants
Q_{x},Q_{y}	plate transverse shear resultants
Q _{ij}	elements of stiffness matrix of layer in natural axis system
$\bar{Q}_{\mathtt{i}\mathtt{j}}$	elements of stiffness matrix of layer in x-y axis system
T	temperature
u, v, w	x, y, z displacements
u _o , v _o	x, y midplane displacements
α	thermal expansion coefficients

NOMENULATURE (Continued)

^{\epsilon} 1-2	strains in natural axis system of a particular layer
$\left[\epsilon_{x-y}\right]$	strains in laminate axis system
[ex-y	midplane strains in laminate axis system
$\begin{bmatrix} \epsilon \stackrel{Q}{x} - y \end{bmatrix}$	plate curvature
$\nu_{12}, \ \nu_{21}$	Poisson's ratios
$\left[\sigma_{1-2} \right]$	stresses in natural axis system of a particular layer
$\left[\sigma_{\mathbf{x-y}}\right]$	stresses in laminate axis system
$\overline{\sigma}_{x-y}$	average stresses in laminate axis system
$ au_{xz}$, $ au_{yz}$	transverse shear stresses

SECTION I

INTRODUCTION

Until recently the point stress analysis of a laminate has been limited to inplane analyses and inplane applications.

Recent composite laminate applications have required a combined inplane and bending point stress analysis. Initial laminated composite applications were, for example, sandwich plate skins which can be assumed to remain flat and thus eliminate curvature terms. With the expanding use and applications of composite elements came a need for a coupled inplane and bending point stress analysis. The present analysis presents the usual lamination theory which allows the derivation of the complete laminate constitutive relation from basic lamina properties. Lamination theory and the current notation in the field may be found in several references, for example: Primer on Composite Materials: Analysis, by Ashton, Halpin and Petit(1)*.

Allowable stress curves or interaction diagrams are important in the design of laminated structures. An interaction diagram for average inplane stresses is three-dimensional and is thus depicted in two-dimensions with the third variable $\overline{\tau}_{xy}$ appearing as cutoff lines. This type of curve or curves for combined

^{*}The numbers in parenthesis refer to the reference list at the end of the report.

inplane and bending stresses would become either too specialized or too difficult to present for normal design purposes.

Two other features which form a part of a laminate point stress analysis are thermally induced stresses and transverse shear stresses. The thermal stress formulation follows the work of Tsai⁽²⁾ by calculating the thermally induced inplane stress and moment resultants. The transverse shear analysis is formulated by making some simplifying assumptions with respect to the classical theory of laminated plates.

The analyses described above should bring together the basic analytical background necessary to perform a complete linear point stress analysis of a laminated composite. The analysis presented in Sections II through VII has been programmed and is described in detail in the appendix. Section VIII describes the type of output which may be obtained with the computer program.

SECTION II

FORMULATION OF LAMINATE CONSTITUTIVE EQUATIONS

2.1 LAMINA CONSTITUTIVE EQUATION

The constitutive relation for an orthotropic layer in a state of plane stress may be written as follows:

$$\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix} \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \gamma_{12} \end{bmatrix}$$
(1)

where,

$$Q_{11} = E_{11}/(1 - \nu_{12} \nu_{21})$$

$$Q_{22} = E_{22}/(1 - \nu_{12} \nu_{21})$$

$$Q_{12} = \nu_{21} E_{11}/(1 - \nu_{12} \nu_{21}) = \nu_{12} E_{22}/(1 - \nu_{12} \nu_{21})$$

$$Q_{66} = G_{12}$$

$$Q_{16} = Q_{26} = 0.$$
(2)

 E_{11} , E_{22} , ν_{12} , and G_{12} are the four independent elastic constants in the 1-2 axis system of the layer. Thus the stresses σ_1 , σ_2 , τ_{12} and the strains ϵ_1 , ϵ_2 , τ_{12} are also in the layer axis system (see Figure 1). Transforming Equation 1 into the laminate x-y axis system results in

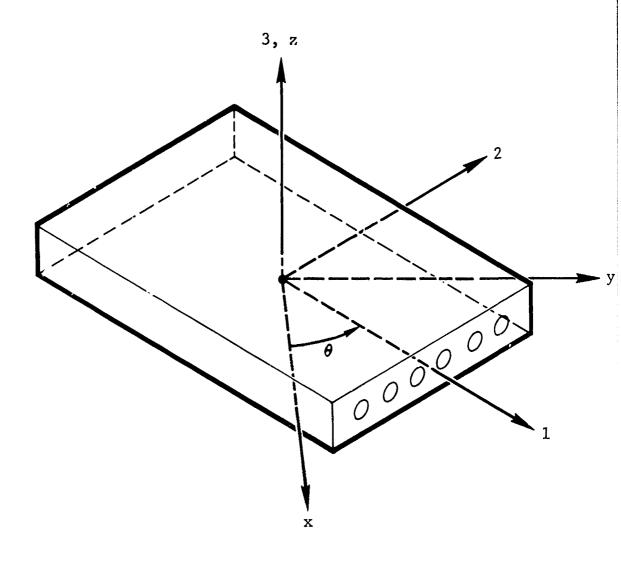


Figure 1 Larina (1-2) and Laminate (x-y) Axis System

$$\begin{bmatrix} \sigma_{\mathbf{x}} \\ \sigma_{\mathbf{y}} \\ \tau_{\mathbf{x}\mathbf{y}} \end{bmatrix}_{\mathbf{k}} = \begin{bmatrix} \overline{\mathbf{Q}}_{11} & \overline{\mathbf{Q}}_{12} & \overline{\mathbf{Q}}_{16} \\ \overline{\mathbf{Q}}_{12} & \overline{\mathbf{Q}}_{22} & \overline{\mathbf{Q}}_{26} \\ \overline{\mathbf{Q}}_{16} & \overline{\mathbf{Q}}_{26} & \overline{\mathbf{Q}}_{66} \end{bmatrix}_{\mathbf{k}} \begin{bmatrix} \epsilon_{\mathbf{x}} \\ \epsilon_{\mathbf{y}} \\ \gamma_{\mathbf{x}\mathbf{y}} \end{bmatrix}_{\mathbf{k}}$$
(3)

where the \overline{Q}_{ij} are the transformed stiffnesses and k presents the kth layer of the laminate. This transformation represents a rotation of 1-2 system into the x-y system through the angle θ . Equation 3 may also be written as,

$$\left[\sigma\right]_{k} = \left[\overline{Q}\right]_{k} \left[\epsilon\right]_{k} .$$
 (4)

2.2 STRAIN-DISPLACEMENT EQUATIONS

The displacements at any point of a cross-section may be written

$$u = u_{0} - z \frac{\partial w}{\partial x}$$

$$v = v_{0} - z \frac{\partial w}{\partial y}$$

$$w = w_{0}$$
(5)

where u, v, and w represent the displacements in the x, y and z directions respectively. The midplane displacements are given by u_0 , v_0 , and w_0 . The strain-displacement relations are given as

$$\epsilon_{x} = \frac{\partial u}{\partial x}$$

$$\epsilon_{y} = \frac{\partial v}{\partial y}$$

$$\epsilon_{y} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}.$$
(6)

Now substituting Equations 5 into Equations 6:

المراق والماما والمراء والمراء والمراق والمراق والمراء والمراء والمراوا والماليان والمراوي والمروي والمراوي والمراوي

$$\epsilon_{x} = \frac{\partial u_{0}}{\partial x} - z \frac{\partial 2w}{\partial x^{2}}$$

$$\epsilon_{y} = \frac{\partial v_{0}}{\partial y} - z \frac{\partial 2w}{\partial y^{2}}$$

$$\gamma_{xy} = \frac{\partial u_{0}}{\partial y} + \frac{\partial v_{0}}{\partial x} - 2z \frac{\partial 2w}{\partial x \partial y}$$
(7)

or

$$\epsilon_{x} = \epsilon_{y}^{o} + z k_{x}$$

$$\epsilon_{y} = \epsilon_{y}^{o} + z k_{y}$$

$$\gamma_{xy} = \gamma_{xy}^{o} + z k_{xy}$$
(8)

where, ϵ_x^0 , ϵ_y^0 , γ_{xy}^0 represent midplane strains and k_x , k_y , k_{xy} represent plate curvatures. These equations may be written as,

$$\begin{bmatrix} \epsilon_{\mathbf{x}} \\ \epsilon_{\mathbf{y}} \\ \gamma_{\mathbf{xy}} \end{bmatrix} = \begin{bmatrix} \epsilon_{\mathbf{x}}^{0} \\ \epsilon_{\mathbf{y}}^{0} \\ \gamma_{\mathbf{xy}}^{0} \end{bmatrix} + \mathbf{z} \begin{bmatrix} k_{\mathbf{x}} \\ k_{\mathbf{y}} \\ k_{\mathbf{xy}} \end{bmatrix}$$

or

$$\left| \epsilon \right| = \left| \epsilon^{0} \right| + z \left| k \right|.$$
 (9)

Now, substituting Equation 9 into Equation 4 results in,

Equation 10 may be used to calculate the stresses at any point z and thus in any layer of the laminate if the midplane strains $\left| \begin{smallmatrix} \varepsilon \end{smallmatrix} \right|$ and curvatures $\left| \begin{smallmatrix} k \end{smallmatrix} \right|$ are known.

2.3 LAMINATE CONSTITUTIVE EQUATIONS

With the exception of defining the stress (N_x, N_y, N_{xy}) and moment (M_x, M_y, M_{xy}) resultants, the background material for the formulation of the laminate constitutive equations has been presented. The stress and moment resultants represent a system which is statically equivalent to the stress system that is acting on the laminate. These stress and moment resultants are shown in Figure 2. They are defined as follows:

$$\begin{bmatrix} N_{x} \\ N_{y} \\ N_{xy} \end{bmatrix} = \int_{-h/2}^{h/2} \begin{bmatrix} \sigma_{x} \\ \sigma_{y} \\ \tau_{xy} \end{bmatrix} dz$$
 (11)

and,

$$\begin{bmatrix} M_{x} \\ M_{y} \\ M_{xy} \end{bmatrix} = \int \frac{h/2}{\sigma_{x}} \begin{bmatrix} \sigma_{x} \\ \sigma_{y} \\ \tau_{xy} \end{bmatrix} zdz . \qquad (12)$$

By substituting Equation 10 into Equations 11 and 12 and separating the continuous integral into a sum of discrete

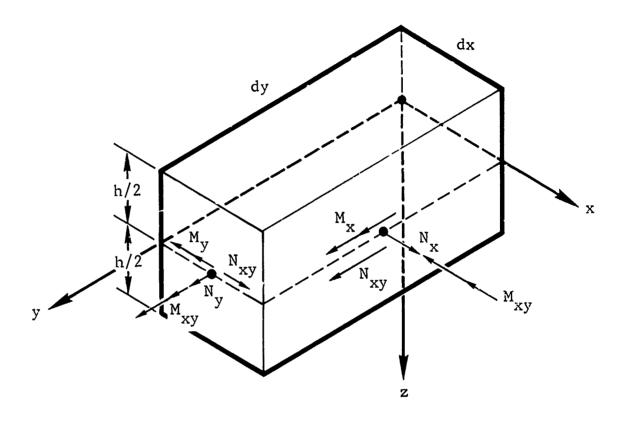


Figure 2 Stress and Moment Resultants

integrals across each layer of an n layered laminate results in:

$$\left[N\right] = \sum_{k=1}^{n} \left\{ \int_{h_{k-1}}^{h_{k}} \left[\overline{Q}\right]_{k} \left[\epsilon^{o}\right] dz + \int_{h_{k-1}}^{h_{k}} \left[\overline{Q}\right]_{k} \left[k\right] z dz \right\}$$
(13)

and

$$\left[M\right] = \sum_{k=1}^{n} \left\{ \int_{h_{k-1}}^{h_{k}} \left[\overline{Q}|_{k} \left[\epsilon^{0}\right] z dz + \int_{h_{k-1}}^{h_{k}} \left[\overline{Q}|_{k}|_{k}\right] z^{2} dz \right\}. \quad (14)$$

The notation for a particular lamina within a laminate is shown in Figure 3. Since $\begin{bmatrix} \epsilon^0 \end{bmatrix}$ and $\begin{bmatrix} k \end{bmatrix}$ are constant across the laminate and $\begin{bmatrix} \overline{Q} \end{bmatrix}_k$ is constant within any layer, the integrals in Equations 13 and 14 may be evaluated. Equations 13 and 14 thus may be reduced to the following.

and,

$$\begin{bmatrix} M \end{bmatrix} = \begin{bmatrix} B \end{bmatrix} \begin{bmatrix} \epsilon^{0} \end{bmatrix} + \begin{bmatrix} D \end{bmatrix} \begin{bmatrix} k \end{bmatrix}$$
 (16)

where

$$A_{ij} = \sum_{k=1}^{n} (Q_{ij})_{k} (h_{k}-h_{k-1})$$
 (17)

$$B_{ij} = 1/2 \sum_{k=1}^{n} (Q_{ij})_{k} (h_{k}^{2} - h_{k=1}^{2})$$
 (18)

$$D_{ij} = 1/3 \sum_{k=1}^{n} (Q_{ij})_k (h_k^3 - n_{k-1}^3).$$
 (19)

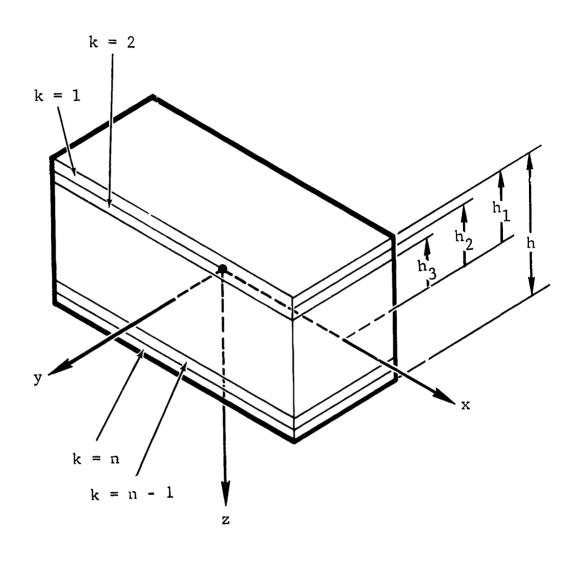


Figure 3 Lamina Notation

Combining Equations 15 and 16 results in:

$$\begin{bmatrix} N \\ M \end{bmatrix} = \begin{bmatrix} A & B \\ B & D \end{bmatrix} \begin{bmatrix} \epsilon^{\circ} \\ k \end{bmatrix}. \tag{20}$$

Equation 20 is the total constitutive relation for a laminated plate. The coupling of inplane and bending is apparent in Equation 20 by the presence of the B submatrix. For a midplane symmetric laminate the B matrix is zero and thus the actions of bending and stretching uncouple.

SECTION III

CALCULATION OF LAMINA STRESSES AND STRAINS FOR AVERAGE INPLANE STRESSES

In order to evaluate the stresses and strains in the lamina of a laminate when average inplane stresses are known, the constitutive equation is assumed to be uncoupled. Thus, Equation 20 results in:

$$\begin{bmatrix} N_{x} \\ N_{y} \\ N_{xy} \end{bmatrix} = \begin{bmatrix} A \end{bmatrix} \begin{bmatrix} \epsilon^{\circ}_{x} \\ \epsilon^{\circ}_{y} \\ \gamma^{\circ}_{xy} \end{bmatrix}. \tag{21}$$

This equation is converted to an average stress analysis equation by dividing by the laminate thickness t, thus:

$$\begin{bmatrix} \overline{\sigma}_{x} \\ \overline{\sigma}_{y} \\ \overline{\tau}_{xy} \end{bmatrix} = \begin{bmatrix} A/t \end{bmatrix} \begin{bmatrix} \epsilon^{o}_{x} \\ \epsilon^{o}_{y} \\ \gamma^{o}_{xy} \end{bmatrix}.$$
 (22)

The input average stresses may be input at some angle to the laminate axis. These stresses are first rotated into the laminate axis system to obtain the stresses in Equation 22. Therefore for a given set of average laminate stresses, Equation 22 may

be used to calculate the laminate and thus the lamina strains in the laminate axis system. These strains are next rotated into the particular lamina natural axis system. The lamina constitutive equation (Equation 1) may then be used to convert the lamina strains into stresses.

SECTION IV

INTERACTION DIAGRAMS

A laminate interaction diagram is snown in Figure 4. This diagram is based on the maximum strain theory of failure for each lamina in the laminate and depicts allowable average stresses for a particular laminate. This diagram is in reality three dimensional in $\overline{\sigma}_{x}$, $\overline{\sigma}_{y}$, and $\overline{\tau}_{xy}$, where the bar indicates average stresses. The laminate interaction diagram thus represents a way of checking stress levels from a conventional stress analysis. If the stress state falls inside the envelope no lamina in the laminate will fail in any mode of the maximum strain theory of failure. These diagrams may be developed for many different laminates and used by a designer in setting thicknesses and orientations.

In order to determine these diagrams, all combinations of unit average stresses are applied to a specified laminate. Next, the strains ϵ_1 , ϵ_2 , and γ_{12} are determined for each lamina in the laminate for all combinations of the unit stresses. These strains are in the natural axis system of the particular lamina. These strains are calculated as described in Section III. Now, since these lamina strains were produced by unit average laminate stresses, the stresses can be ratioed up to some allowable stress

if allowable lamina strains are known. Thus, for a particular shear stress, an allowable set of $\overline{\sigma}_x$ and $\overline{\sigma}_y$ is obtained for each type of failure in each lamina of the laminate.

By plotting these $\overline{\sigma}_x$ and $\overline{\sigma}_y$ intercepts for the various failure modes for all layers in the laminate, an interaction diagram is obtained. Figure 4 shows the various failure mode cutoffs for a particular laminate. This diagram is the minimum envelope of all the failure mode lines. This procedure is repeated for shear increments of \pm 10,000 psi from zero to a maximum allowable. The maximum allowable shear stress is obtained from the procedure of applying unit stresses.

In the past, the computer had been used to compute the $\overline{\sigma}_X$ and $\overline{\sigma}_y$ intercepts for the various failure modes. These modes were then hand plotted to produce the desired interaction diagram. A search routine to compute the final coordinates of the interaction diagram for a laminate has been written, and is part of the program described in Appendix I.

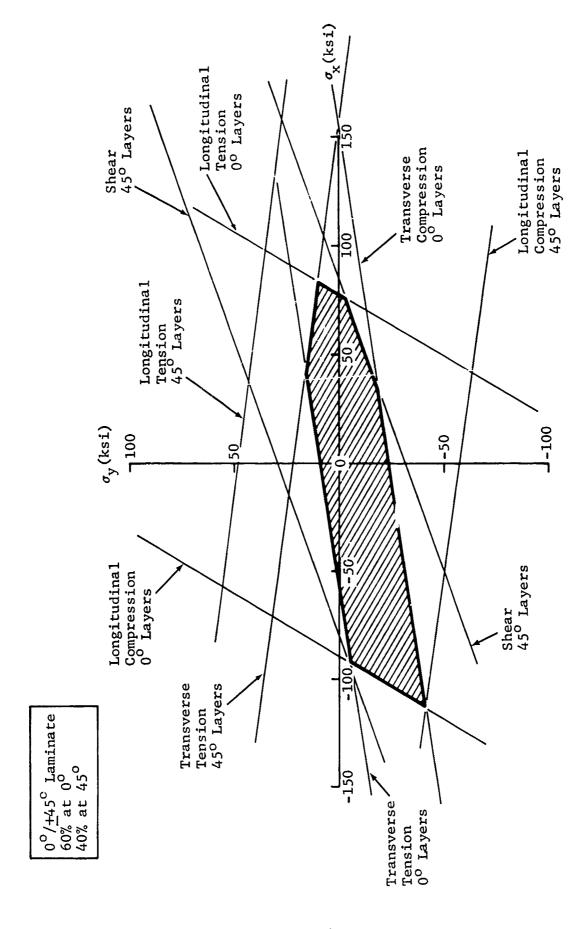


Figure 4 Laminate Interaction Diagram

SECTION V

COMPLETE POINT STRESS ANALYSIS

A complete point stress analysis of a laminate under an arbitrary set of loads includes both inplane and bending loads. The inverted form of Equation 20 is used for this analysis:

$$\begin{bmatrix} \epsilon^{0} \\ k \end{bmatrix} = \begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix} \begin{bmatrix} N \\ M \end{bmatrix}. \tag{23}$$

If the laminate is midplane symmetric, the submatrix B in Equation 20 is zero. With this matrix zero, the B' and C' matrices in Equation 23 are zero, and thus the inplane and bending effects uncouple. With known inplane stress resultants (N_x, N_y and N_{xy}) and moments (M_x, M_y and M_{xy}), Equation 23 may be used to calculate the midplane strains (ϵ^{o}_{x} , ϵ^{o}_{y} and γ^{o}_{xy}) and curvatures (k_x, k_y and k_{xy}). The state of strain at any point across the thickness of the laminate may now be determined by using Equation 9. Since the $|\epsilon|_{k}$ vector is still in the x-y coordinate system of the laminate, it must be transformed into the natural axis system for the particular lamina in question. The particular lamina constitutive relation, Equation 1, may now be

used to compute lamina stresses. These lamina stresses and or strains may then be used to calculate margins of safety from a failure criteria. This completes the point stress analysis in that the complete state of stress and strain has been determined in every layer of the laminate.

SECTION VI

THERMALLY INDUCED STRESSES

The thermal expansion problem can be approached by calculating the thermally induced inplane stress $\left\lceil N^T \right\rceil$ and moment $\left\lceil M^T \right\rceil$ resultants using

$$\left[N^{T}\right] = (-T) \int_{-h/2}^{h/2} \left[Q\right] \left[\alpha\right] dz,$$
 (24)

and

$$\left[\mathbf{M}^{\mathrm{T}} \right] = (-\mathrm{T}) \int_{-\mathrm{h}/2}^{\mathrm{h}/2} \left[\mathbf{Q} \right] \left[\alpha_{1}^{\dagger} \mathbf{z} \, d\mathbf{z}, \right]$$
 (25)

as presented in Reference (?). The |Q| and $|\alpha|$ matrices in the above equations are the lamina stiffness matrix and the vector of thermal expansion coefficients respectively in the lamina natural axis system. The product of |Q| and $|\alpha|$ must be rotated into the laminate x-y coordinate system before the integration is carried out. With the lamination temperature assumed as the zero stress state, -T, is the change from this lamination temperature. Note that (-T) is outside the integral, thus assuming a constant temperature across the thickness of the laminate. After the thermally induced stress $|N^T|$ and moment $|M^T|$ resultants have been found by using Equations 24 and 25, the point stress analysis proceeds as described in Section V. Thus with this type of

formulation, the thermally induced inplane and moment resultants may be considered separately or added to corresponding resultants produced from other types of loadings.

SECTION VII

INTERLAMINAR SHEAR STRESSES

The interlaminar shear calculations for $\tau_{\rm xz}$ and $\tau_{\rm yz}$ were approached by making some simplifying assumptions. These assumptions will be pointed out in the following discussion. The shear resultants $Q_{\rm x}$ and $Q_{\rm y}$ were obtained from Reference (3) as,

$$Q_{x} = B_{11} u^{o},_{xx} + 2B_{16} u^{o},_{xy} + B_{66} u^{o},_{yy} + B_{16} v^{o},_{xx}$$

$$+ (B_{12} + B_{66}) v^{o},_{xy} + B_{26} v^{o},_{yy} - D_{11} w,_{xxx}$$

$$- 3D_{16} w,_{xxy} - (D_{12} + 2D_{66}) w,_{xyy} - D_{26} w,_{yyy}$$
(26)

and

$$Q_{y} = B_{16} u^{o},_{xx} + (B_{12} + B_{66}) u^{o},_{xy} + B_{26} u^{o},_{yy} + B_{66} v^{o},_{xx}$$

$$+ 2B_{26} v^{o},_{xy} + B_{22} v^{o},_{yy} - D_{16} w,_{xxx}$$

$$- (D_{12} + 2D_{66}) w,_{xxy} - 2D_{26} w,_{xyy} - D_{22} w,_{yyy}$$
(27)

where B_{ij} and D_{ij} are the same terms as in Equations (18) and (19) and u^0 , v^0 and w are the midplane deflections. Equations 26 and 27 reduce to the following for midplane symmetric laminates:

$$Q_x = -D_{11} w_{,xxx} - 3D_{16} w_{,xxy} - (D_{12} + D_{66}) w_{,xyy} - D_{26} w_{,yyy},$$
 (28)

and

$$Q_y = -D_{16} w_{,xxx} - (D_{12} + 2D_{66}) w_{,xxy} - 2D_{26} w_{,xyy} - D_{22} w_{,yyy}.$$
 (29)

Next, the cross-derivative terms are neglected resulting in

$$Q_x = -D_{11} w_{,xxx} - D_{26} w_{,yyy},$$
 (30)

and

$$Q_y = -D_{16} w_{,xxx} - D_{22} w_{,yyy}.$$
 (31)

Now by using Q_x and Q_y as known or input data, Equations 30 and 31 may be solved to obtain expressions for $w_{,xxx}$ and $w_{,yyy}$:

$$w_{,xxx} = \frac{1}{D} \left[-D_{22} Q_x + D_{26} Q_y \right]$$
 (32)

and

$$w_{yyy} = \frac{1}{D} \left[D_{16} Q_x - D_{11} Q_y \right]$$
 (33)

where

$$D = D_{11} D_{22} - D_{16} D_{26}. (34)$$

The interlaminar shear stresses are given as

$$\tau_{xz}^{(k)} = \frac{z^2}{2} \left[\overline{Q}_{11}^{(k)} w,_{xxx} + \overline{Q}_{26}^{(k)} w,_{yyy} \right] + f^{(k)}(x,y), \qquad (35)$$

and

$$\tau_{yz}^{(k)} = \frac{z^2}{2} \left[\overline{Q}_{16}^{(k)} w_{,xxx} + \overline{Q}_{22}^{(k)} w_{,yyy} \right] + g^{(k)} (x,y)$$
 (36)

after cross-derivative terms and inplane deformation terms are neglected (Reference 3). The \overline{Q}_{ij} terms are the lamina stiffness terms rotated into the x-y coordinate system. The functions $f^{(k)}(x,y)$ and $g^{(k)}(x,y)$ are determined by using the boundary conditions that τ_{xz} and τ_{yz} are zero at the surface of the plate. The final form of $\tau_{xz}^{(k)}$ and $\tau_{yz}^{(k)}$ is

والعرا وبالدائع وماعران المعامين المعاهدة المعاهدة المعادي المدائدة وياحا وبالدوا والمعارين والمعامل

$$\tau_{xz}^{(k)} = (\frac{1}{8}) (4z^2 - h^2) \left[\overline{Q}_{11}^{(k)} w_{,xxx} + \overline{Q}_{25}^{(k)} w_{,yyy} \right],$$
 (37)

and

$$\tau_{yz}^{(k)} = (\frac{1}{8}) (4z^2 - h^2) \left[\overline{Q}_{16}^{(k)} w,_{xxx} + \overline{Q}_{22}^{(k)} w,_{yyy} \right]$$
 (38)

where h is the total laminate thickness. Thus by solving Equations (32) and (33) for w, $_{\rm XXX}$ and w, $_{\rm Yyy}$, Equations (37) and (38) result in values of $\tau_{\rm XZ}$ and $\tau_{\rm YZ}$ at any point of the crosssection. The shear stresses resulting from the use of Equations (37) and (38) are based on two assumptions: (1) midplane symmetric laminates, and (2) neglect of the effects of the cross-derivative terms which appear in the $\rm Q_{\rm X}$ and $\rm O_{\rm Y}$ equations. The effect of the midplane symmetric assumption is clearly not significant in many cases since most laminates used in actual design are midplane symmetric. The effect of neglecting the cross-derivative term is the same as assuming the plate acts like an uncoupled beam in both directions. It is felt that this is not a serious assumption for the first pass effort at obtaining interlaminar shear stresses.

SECTION VIII

ANALYTICAL RESULTS

The analysis described in the preceeding sections has been programmed for an IBM 360-65 digital computer as program SQ5. The original program U65 was written by M. E. Waddoups. The following is a brief paragraph describing the results obtained for each of the major contributions of the program.

8.1 INTERACTION DIAGRAM

Figure 3 shows an interaction diagram obtained from the procedure SQ5. As stated earlier, the program prints out the $\overline{\sigma}_{x}$ and $\overline{\sigma}_{y}$ coordinates of the corners of the interaction diagram. The user then plots these points and connects them with straight lines to obtain the interaction diagram for a particular $\overline{\tau}_{xy}$ value. The $\overline{\tau}_{xy}$ value is printed out along with the $\overline{\sigma}_{x}$ and $\overline{\sigma}_{y}$ coordinates.

Lamina strain allowables must be input along with the usual lamina properties such as thickness and orientation in order to compute the interaction diagram coordinates.

8.2 BENDING ANALYSIS

In order to check the bending analysis subroutine in SQ5, data from a standard 0° flexure test was used. SQ5 predicted

the expected Mc/EI strain to be 7026 μ in/in, while experimentally a value of 7100 μ in/in.was obtained with the use of strain gages. A test program which will include cross-ply beams will be initiated at a later date.

8.3 INTERLAMINAR SHEAR

The interlaminar shear stress distribution calculations in SQ5 have been checked for a m.dplane symmetric laminated beam. The distribution checked very close to the distribution obtained from a photoelastic coating on an experimental beam. A midplane symmetric laminate and beam action were the two basic assumptions in the interlaminar shear stress derivation, thus very good results were expected and obtained for this situation.

8.4 THERMAL EXPANSION ANALYSIS

The thermal analysis section of SQ5 has been checked by comparison with a $\pm 15^{\circ}$ glass laminate by Tsai (Reference 2). The coefficients of thermal loads (N^T and M^T) obtained from SQ5 check the results of Tsai.

This analysis also produces the laminate coefficients of thermal expansion. As an example of the accuracy obtained, 30.5 predicted an α_1 of 3 x 10^{-6} for a $0^{\circ}/\pm60^{\circ}$ boron laminate while a value of 3.25 x 10^{-6} has been obtained experimentally.

SECTION IX

SUMMARY

An existing computer program, U65, has been updated and expanded in several respects. The major changes are as follows:

(1) a point stress bending analysis using the full laminate constitutive equation has been included, (2) thermally induced moments and inplane stress resultants may be included in a point stress analysis, and (3) a simplified interlaminar shear stress analysis based on beam action and midplane symmetry has been added. The overall program was also modified to make it more efficient from the users point of view as well as machine efficiency.

Several basic checks were performed and the program should now become the laminate analysis program for use in linear analyses.

APPENDIX I

DESCRIPTION OF COMPUTER PROGRAM SQ5

The analysis presented in Sections II through VII has been programmed as computer program SQ5. The forerunner of the present program was U65. The program SQ5 consists of a main program and seven subroutines, four of which were added in producing SQ5. In summary, U65 was modified as follows in producing the computer program SQ5:

- 1. The input was completely revised.
- 2. The input data was written out as the first item of output
- 3. The input and output were updated to the current notation of Reference 1
- 4. A point stress bending analysis was added
- 5. A laminate thermal stress analysis was added
- 6. A search routine for the interaction diagram coordinates
 was added (written by R. W. McMickle)
- A simplified interlaminar shear stress analysis routine was added.
- 8. Multiple option capability was added whereby many parts of the program can be used with a single problem input

The function of each subroutine is described below. A description of each card entry will be given in Appendix II.

MAIN Program

The MAIN program is used to read and write out the input data. The input data is written out with identifying information in order to facilitate a check of the problem data. Current notation is used for all the output data. Next, the main program computes the laminate constitutive relation (Equation 20).

The remainder of the main program decides which of the subroutines will be called according to a list of option keys which have been input.

Subroutine STEC

This subroutine computes laminate strains for all combinations of unit average stresses. These laminate strains are needed for interaction diagram calculations. If a point stress analysis using input average stresses is to be performed, this subroutine rotates the input stresses (they may be input at some angle to the laminate axis) into the laminate x-y axis and computes the corresponding laminate strains.

Subroutine SSRC

This subroutine rotates the laminate strains found in STEC into the natural axis system of each layer in the laminate.

Using the lamina constitutive relation, these strains are used to calculate lamina stresses. Margins of safety are also calculated from the lamina strains. If an interaction diagram was

called for, allowable lamina stresses are calculated as described in Section IV.

Subroutine SURFS

Subroutine SURFS calculates the $\overline{\sigma}_{X}$ and $\overline{\sigma}_{y}$ cutoff allowable stresses which are used in plotting an interaction diagram. First, the laminate strains found in subroutine STEC are rotated into the natural axis system of each lamina in the laminate. Not since these strains were produced by unit stresses, allowable stresses can be calculated by ratioing with an allowable strain. This procedure is repeated for all combinations of unit stresses and for increments of $\overline{\tau}_{Xy}$. $\overline{\tau}_{Xy}$ is initially set equal to zero and then increased in increments of $\pm 10,000$ psi, until the maximum value is reached. The negative increments of $\overline{\tau}_{Xy}$ are necessary only for non-rotationally symmetric laminates. The final coordinates of the interaction diagram reflect the minimum envelope for both + and - $\overline{\tau}_{xy}$ increments. The maximum value of $\overline{\tau}_{xy}$ was calculated in subroutine STEC.

Subroutine SURFS next calls subroutine ISECT which will be described in the following paragraph.

Subroutine ISECT

This subroutine was written by R. W. McMickle and is a highly specialized search routine for the final coordinates of the interaction diagram. ISECT is called one time for each

increment of $\overline{\tau}_{xy}$, thus all the interaction diagram coordinates are printed for each $\overline{\tau}_{xy}$ interval. The subroutine uses the $\overline{\sigma}_{x}$ and $\overline{\sigma}_{y}$ intercepts for the various failure modes which were calculated in subroutine SURFS. The $\overline{\sigma}_{x}$ and $\overline{\sigma}_{y}$ intercepts are also printed and may be used to obtain the desired interaction diagram if the user wishes to see which of the modes control the various failure lines.

Subroutine BEND

Subroutine BEND first computes the inverse of the laminate constitutive equation (Equation 23). Next, the subroutine prints Equation 23 and uses it to calculate the laminate midplane strains and curvatures (see Section V). These quantities are then used to calculate the state of stress and strain in each lamina of the laminate.

Subroutine TEMP

Subroutine TEMP uses Equations 24 and 25 to calculate the thermally induced inplane stress and moment resultants. The laminate coefficients of thermal expansion are also calculated in this subroutine.

Subroutine SHEAR

Subroutine SHEAR first calculates the third derivatives of w with respect to x and y using Equations 32 and 33. Next,

Equations 37 and 38 are used to calculate $\overline{\tau}_{xz}$ and $\overline{\tau}_{yz}$ at each lamina interface across the thickness of the laminate. This distribution is printed along with the corresponding z position within the laminate.

APPENDIX II

INPUT DATA DESCRIPTION

The input consists of problem card deck(s). Data contained in the problem deck(s) will consist of integers and real numbers. All integers must be right adjusted in the proper card field. Real numbers must contain a decimal point in the proper position. The general content of each card in a problem deck is as follows:

Columns

1-66	Input data
67 - 72	Six digit job number obtained from the Computing Laboratory
73	The alphabetic letter "P"
74 - 75	Number each problem within a problem deck sequentially from 01
76-79	Number each card within a problem sequentially from 0001

Card Descriptions

Contents

Card 1:

Column

1	Blank
2-66	Problem title or identifying information which will
	be printed at the top of the first page of the
	problem output. Any alphabetic or numeric symbol
	may be used.

Card 2: (815) Column Contents 1-5 KEY 1 = 1-Program terminates after computing and writing out the elements of the constitutive matrices (See Equation 20) = 0-Program operation continues after computation of laminate data. 6-10 KEY 2 = 1-A point stress analysis will be made on input sets of N and M. One card per load case must be added to the problem deck. This key must also be set equal to one if a thermal analysis is to be performed. = 0-No point stress or thermal analysis will be done. 11-15 KEY 3 = 1-A point stress analysis will be made of average stresses σ_{α} , σ_{β} , $\tau_{\alpha\beta}$, and θ . θ is the angle at which the stresses are applied. This analysis is for inplane loads only. = 2-An interaction diagram will be computed for the input laminate. KEY 4 = 1-Thermally induced inplane $|N^T|$ and moment 16-20 $|M^T|$ resultants will be computed for an

be set equal to 1.

input temperature. If KEY 4 = 1, KEY 2 must

Column	Content
	= 0-No thermal analysis will be made.
21-25	KEY 5 = 1-An interlaminar shear stress analysis will
	be made for input values of $Q_{\mathbf{x}}$ and $Q_{\mathbf{y}}$.
	= 0-No interlaminar shear stress analysis
	will be made.
26-30	MA = Number of layers in the laminate (max. no. =
	400).
31-35	NOMAT = Number of material types (max. no. = 400).
36-40	NCL = Number of loading cases. This applies to
	sets of $[N]$ and $[M]$, temperatures, and $Q_{\mathbf{x}}$,
	Q_{v} . (max. no. = 10).

Third Group of Cards: (7F9.0)

Column	Contents
1-9	El(1) - Modulus of elasticity along the first or
	l lamina axis.
10-18	E2(1) - Modulus of elasticity along the second or
	2 lamina axis which is orthogonal to the 1
	lamina axis.
19-27	U1(1) - First poisson's ratio
28-36	G(1) - Shear modulus of elasticity
37-45	ALPHA1(1) - Coefficient of thermal expansion in
	the 1 lamina direction.

Column	Contents
46-54	ALPHA2(1) - Coefficient of thermal expansion in the
	2 lamina direction.
55-63	ALPHA6(1) - Shearing coefficient of thermal expansion.

Additional cards of this type are added for each type of material in the laminate up to NOMAT as input previously. A maximum 400 such cards may be used. Thus, a different material type may be assigned for each layer in the laminate up to the maximum number of layers which is allowed.

Fourth Group	of Cards:	(215,	2F10.0)

Column	Contents
1 - 5	LAY - Layer number
6-10	MATYPE(1) - Material type number
11-20	TH(1) - Counterclockwise angle from the laminate
	reference axes (x,y) to the lamina natural
	axes (1,2). The angle is input in degrees.
21-30	AT(1) - Lamina thickness.

Additional cards of this type are added for each lamina in the laminate up to MA as input previously. A maximum of 400 layers may be input as described.

Fifth Group of Cards: (6F10.0)

Column	Contents
1-10	CALE1(1) - Compression limit strain allowable in
	the 1 lam ina direction.
11-20	CALE2(1) - Compression limit strain allowable in
	the 2 lamina direction.
21-30	CALE3(1) - Negative limit shear strain allowable.
31-40	TALE1(1) - Tension limit strain allowable in the
	1 lamina direction.
41-50	TALE2(1) - Tension limit strain allowable in the
	2 lamina direction.
51-60	TALE3(1) - Positive limit shear strain allowable.

Additional cards of this type are added for each type of material in the laminate up to NOMAT as input previously.

Sixth Group of Cards: (7F9.0) (Optional)

Column	<u>Contents</u>
1-9	N(1,1) - Inplane force resultant in the X-direction
	for load case 1 (lbs/in.).
10-18	N(1,2) - Inplane force resultant in the Y-direction
	for load case 1 (lbs/in.).
19-27	N(1,3) - Inplane shear force resultant for load case
	1 (lbs/in.).
28-36	$M(1,1)$ - M_{x} moment resultant for load case 1
	(in the /in)

Column	Contents
37-45	M(1,2) - My moment resultant for load case 1
	(in.lbs./in.).
46-54	M(1,3) - M _{xy} moment resultant for load case 1
	(in.1bs./in.).
55-63	T(1) - Change in temperature for load case 1
	(+ or - with respect to the lamination
	temperature).

Additional cards of this type are added for each load case up to NLC as input on Card 2. A maximum of 10 load cases may be input. This group of cards is optional in that it would be omitted if (1) laminate properties only were desired, (2) an interaction diagram only were desired, and (3) only interlaminar shear stresses were desired.

Seventh Card: (6F10.0) (Optional)

Column	Contents
1-10	SIG1 - Average laminate stress $^{\sigma}\! lpha$ acting in $lpha$
	direction of an (α, β) system at some angle
	PH1 from the laminate (x,y) axis system.
11-20	SIG2 - Average laminate stress
21-30	SIG3 - Average laminate shearing stress
31-40	PH1 - Angle in degrees from the ($lpha$, eta) system
	to the (x.v) axis system.

This card is input only if KEY3 = 1 and KEY1 = KEY2 = KEY4 = 0.

Eighth Group of Cards: (6F10.0) (Optional)

Column	Contents
1-10	QX(1) - X shear force resultant for load case 1
	(lbs./in.).
11-20	QY(1) - Y shear force resultant for load case 1
	(lbs./in.).
21-30	QX(2) - X shear force resultant for load case 2
	(lbs./in.).
31-40	QY(2) - Y shear force resultant for load case 2
	(lbs./in.).
41-50	QX(3) - X shear force resultant for load case 3
	(lbs./in.).
51-60	QY(3) - Y shear force resultant for load case 3
	(lbs./in.).

Additional cards are added as needed until the number of load cases (NLC) has been fulfilled. These cards are input only if KEY5 = 1.

Output Data

All the input data are printed with identifying information.

This listing may be used as a check for input errors. The output

data are printed with appropriate headings and information and is thus self-explanatory. Appendix I also contains information on the output of the various subroutines.

Restrictions

The number of layers (MA) and the number of material types (NOMAT) may range from 1 to a maximum of 400. The maximum number of loading conditions is set at 10. The other restrictions on the program are in the use of the KEY options. These options were discussed earlier, and Figure 5 contains a flow chart showing which combinations of output may be obtained with one problem input.

Estimate of Running Time

The run time may be estimated using:

 $T \text{ (minutes)} = 0.3 + (0.1) \cdot N$

where,

N = number of problems.

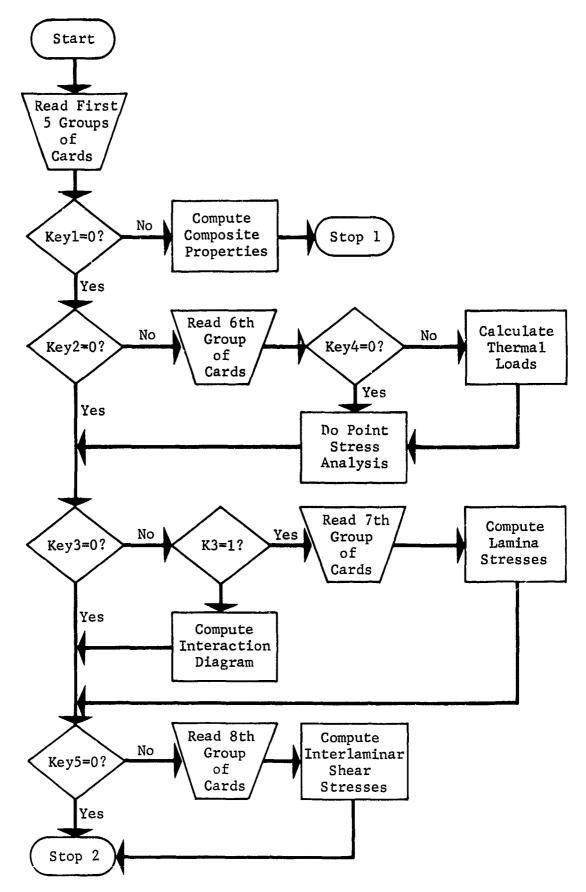


Figure 5 SQ5 Flow Diagram

APPENDIX III

PROGRAM LISTING

```
$35,001
      COMMON AL(3.3). CALF1(400). CALF2(400). CALF3(400). TALE1(400).
                                                                                $250002
     1 TALE2(400). TALE3(400). ADT(3.3). TH(400). Q11(400). D12(400).
                                                                                SQ 50 00 3
     2 Q22(400), Q66(400), BLF(18), A(3,3), B(3,3), D(3,3), AH(401),
     3 AT(400), E1(400), E2(400), U1(400), U2(400), C(400), S81(18),
                                                                                5053004
     4 OBAR(430.3.3). GAM(3.400.3). SLA(400). SZA(400). S3A(400).
                                                                                3250005
                                                                                $957906
     5 SJ(1230). S(50). Y(50), Y(50), XN(50). YN(50), FX(3), FY(3).
     6 SIGX(1200), SIGY(1200), MATYPE(400)
                                                                                5050007
      COMMON BSTAR(3.3), CSTAR(3.3), DSTAR(3.3), DSTARI(3.3), BDC(3.3), SQ50008
     1 APFIME(3.3). BPRIME(3.3). CPRIME(3.3). DPRIME(3.3). ASTAR(3.3).
                                                                                5050009
     2 BAB(3,3), 2(401), AI(3,3), E0(10,3), E(10,401,3), K(10,3),
                                                                                SU 50 01 0
     3 N(10.3). M(10.3). NT(10.3). MT(10.3). OO11(400). QQ22(400).
                                                                                5057011
                                                                                $950012
     4 QQ12(400), Q366(40Q), ALPHAC(400), TAL(3,400), TQA(3,400),
     5 ALPHA1(40C), ALPHA2(490), ALPHA6(400), T(10), 0X(10), QY(10)
                                                                                $050013
      COMMON CO. CO2. SI. SI2. KEYI. KEY2. KEY3. KEY4. KEY5. SICO. SIGI.SQ50014. SIG2. SIG3. PHI. CON. I. J. IZ. I4. M4. NN. DAF. II. LDR. KK. SQ50015
     2 IG. NLC. DAFS. DAFG. ATT. L. MLI. MR. DEL
                                                                                5250016
      REAL K. N. M. NT. MT
                                                                                $950017
      CALL GSTART (3HSJ5,LCP)
                                                                                $95001.8
   10 CALL PROB
                                                                                $950019
                                                                                $950020
                                                                               **5050021
  *** READ IN PROBLEM TITLE
                                                                                $253022
                                                                                5950023
      READ(5.1300)
       WR ITF (6, 1000)
                                                                                5050024
                                                                                $950025
  *** READ IN PRUGLEM DATA
                                                                               *$050026
                                                                                5050027
      READ (5.1010) KEY1. KFY2. KFY3. KEY4. KEY5. MA. NOMAT. NLC
                                                                                $950028
      WRITE(6,5000) KEY1, KFY2, KEY3, KFY4, KFY5, MA, NOMAT, NLC
                                                                                SD 50 02 9
   20 \, \text{DO} \, 30 \, \text{I} = 1.03 \, \text{MAT}
                                                                                SQ 5003 0
      READ (5,1025) E1(I), E2(I), U1(I), G(I), ALPHA1(I), ALPHA2(I),
                                                                                SQ 50 03 1
     1 ALPHA6(I)
                                                                                SQ50032
   30 CONTINUE
                                                                                5050033
                                                                                $050034
      WR ITE (6.5090)
      WR ITF (6,5020)
                                                                                5050035
      WRITE(6,5030) (1,61(1),02(1),U1(1),3(1),ALPHA1(1),ALPHA2(1),
                                                                                SQ51036
     1 \text{ ALPHA6}(I) \cdot I = 1 \cdot \text{NOMAT}
                                                                                5050037
      WRITE (6,5090)
                                                                                $950038
      WRITF (6,5040)
                                                                                5051039
      DO 40 I = 1.M4
                                                                                SQ 50 04 0
      READ (5.1030) LAY, MATYPE(I), TH(I), AT(I)
                                                                                5050041
      WRITE(6,5050) LAY, MATYPE(1), TH(1), AT(1)
                                                                                SQ50042
   40 CONTINUE
                                                                                $950043
      READ (5,1020) (CALF1(I), CALF2(I), CALE3(I), TALF1(I), TALF2(I),
                                                                                $050044
     1 \text{ TALF3}(I), I = 1, NOMAT)
                                                                                5050045
      WR ITF (6.5090)
                                                                                SQ 50 04 6
      WRITE (6,1050)
                                                                                5050047
      HPITE (6.1060) (I. CALEI(I), CALE2(I), CALE3(I), TALEI(I),
                                                                                $951048
     1 TALE2(I), TALE3(I), I = 1, NOMAT )
                                                                                SQ50049
C
                                                                                5050050
C
      LOCATE THE MIDDLE SUPFACE
                                                                                5057051
C.
                                                                                $250052
      '1B = MA + 1
                                                                                SQ51053
      00 50 I2 = 1.48
                                                                                5050054
      \Delta H(12) = 0.0
                                                                                $050055
   50 CONTINUE
                                                                                5953056
```

```
00.60 13 = 2.4R
                                                                             SQ57057
      \Delta H(13) = \Delta T(13-1) + AH(13-1)
                                                                             5957758
                                                                             5050059
   60 CONTINUE
      AHK = AH(MB)/2.0
                                                                             5051060
      00 70 14 * 1,48
                                                                             5050061
      AH(14) = AH(14) - AHK
                                                                             5052062
      ATT = 2.0 AHK
                                                                             5050063
   70 CONTINUE
                                                                             5050064
                                                                             5052065
C
      COMPUTE THE MODULE HE LACH LAYER
                                                                             5050066
C
                                                                             SQ 50067
      DD 80 I5 = 1.44
                                                                             SQ 50068
      16 = MATYPE(15)
                                                                             5050069
      U2(16) = E2(16) / +1(16)*U1(16)
                                                                             5050070
      DEL = 1.0 - U1(16)*(7(16)
                                                                             5050071
      Q11(15) = E1(16) / f(6)
                                                                             5053072
      Q22(15) = F2(16) / Obt
                                                                             5050073
      Q12(15) = Q11(15)*U2(16)
                                                                             SQ50074
      Q66(15) = G(16)
                                                                             5950075
      CUN = TH(15)*0.0174533
                                                                             SQ 50076
      CO = COS(CON)
                                                                             5050077
      CO2 = CO**2
                                                                             SQ 50 078
      03 = 00**3
                                                                             5950079
      0.04 = 0.02 ** 2
                                                                             $050080
      SI = SIN(CON)
                                                                             $050081
      SI2 = SI**2
                                                                             $950082
      SI3 = SI**3
                                                                             SQ50083
      SI4 = SI2**2
                                                                             5050084
      SICC = SI2 * CO2
                                                                             $957085
      OBAP(15,1,1) = O11(15)*CO4 + 2.0*(O12(15) + 2.0*Q66(15))*SICO +
                                                                             $950086
                      222(15)*514
                                                                             5050087
      QBAR(15.1.2) = (J11(15) + Q22(15) - 4.0*266(15))*SICO +
                                                                             5950088
                      012(15)*(SI4 + CO4)
                                                                             SQ50089
      OBAF(15,1,3) = (J11(15) - Q12(15) - 2.0*Q66(15))*CQ3*SI +
                                                                             5Q57090
                      (012(15) - 022(15) + 2.0*966(15))*S13*C1
                                                                             5050091
      98AP(15.2.1) = 98AR(15.1.2)
                                                                             5257092
      QBAP(15,2,2) = Q11(15)*SI4 + 2.0*(Q12(15) + 2.0*Q66(15))*SIC9 +
                                                                             $950093
                      022(15)*004
                                                                             5050094
      QRAF(15,2,3) = (Q11(15) - Q12(15) - 2.0*Q66(15))*S13*CO +
                                                                             5450095
                      (012(15) - 022(15) + 2.0*066(15))*C03*SI
                                                                             $050096
      98AR(15,3,1) = 9849(15,1,3)
                                                                             5057797
      09AP(15,3,2) = JBAP(15,2,3)
                                                                             $050098
      09Ak(15,3,3) = (011(15) + 022(15) - 2.0*012(15) - 2.0*066(15))*
                                                                             5957099
                                                                             5957100
                      SICO + Q66(15)*(SI4 + CO4)
   80 CONTINUE
                                                                             5050101
                                                                             $959102
C
      CUMPINE THE LAMINA
                                                                             $257103
C
                                                                             5050104
      00 \ 100 \ 16 = 1.3
                                                                             5050105
                                                                             5950106
      100 90 \text{ J}6 = 1.3
      A(16.J6) = 0.0
                                                                             $950107
      R(16.J6) = 0.0
                                                                             $950108
                                                                             5050109
      D(16.J6) = 0.0
      ATT(16,J6) = 0.0
                                                                             5050110
   90 CONTINUE
                                                                             5050111
  100 CONTINUE
                                                                             5050112
```

はいろうない。

```
00 \ 130 \ Io = 1.3
                                                                               5050113
                                                                               5050114
      90 120 \text{ Jo} = 1.3
                                                                               SQ 50 115
      D7 110 NN = 1.MA
                                                                               5050116
      A(16.16) = A(16.16) + A(16.16) + A(16.16) = A(16.16)
      B(16+J6) = B(16+J6) + ORAR(NN+16+J6)*(AH(NN+1)**2 - AF(NN)**2)
                                                                               $950117
      D(16+J6) = D(16+J6) + ORAP(NN+16+J6)*(AH(NN+1)**3 - AH(NN)**3)
                                                                               5050118
  110 CONTINUE
                                                                               5050119
                                                                               5050120
  120 CONTINUE
                                                                              5050121
  130 CONTINUE
                                                                               5050122
      nn 150 18 = 1.3
      00.140 \text{ J8} = 1.3
                                                                               5252123
      B(18,J8) = B(18,J8) / 2.0
                                                                               5057124
                                                                               $250125
      0.6 \ \ (8.48) = 0(18.48) \ / 3.0
                                                                               $250126
      TTA \setminus (RU_{\bullet}BI)A = (BU_{\bullet}BI)TDA
                                                                               SQ50127
  140 CONTINUE
  150 CONTINUE
                                                                               $0.50128
r
                                                                               5051129
                                                                               $250130
C
      COMPUTE THE AL MATRIX
C
                                                                               SQ50131
      DET = (A()T(1,1)*A()T(2,2)*A()T(3,3)) + (A()T(1,2)*A()T(2,3)*A()T(3,1)) = S350132
             (40T(1.3)*A0T(2.1)*A0T(3.2)) - (A0T(1.3)*A0T(2.2)*A0T(3.1)) S050133
             (AOT(1,1)*AOT(2,3)*AOT(3,2)) - (AOT(1,2)*AOT(2,1)*AOT(3,3)) (SO 5) 134
                                                                               5051135
      AL(1,1) = (AOT(2,2)*AOT(3,3) - AOT(2,3)*AOT(3,2)) / DET
      AL(1,2) = (AOT(2,3)*AOT(3,1) - AOT(2,1)*AOT(3,3)) / DET
                                                                               5050136
      AL(1+3) = (AOT(2+1)*AOT(3+2) - AOT(2+2)*AOT(3+1)) / DET
                                                                               5950137
      AL(2,2) = (AOT(1,1)*AOT(3,3) - AOT(1,3)*AOT(3,1)) / DFT
                                                                               SQ50138
      AL(2,3) = (AUT(1,2)*AUT(3,1) - AUT(1,1)*AUT(3,2)) / DET
                                                                               5050139
      AL(3,3) = (AOT(1,1)*AOT(2,2) - AOT(1,2)*AOT(2,1)) / DET
                                                                               $250140
                                                                               5050141
      AL(2\cdot 1) = AL(1\cdot 2)
                                                                              $050142
      AL(3.1) = AL(1.3)
                                                                              5050143
      AL(3.2) = AL(2.3)
                                                                              5050144
      00 \ 155 \ I = 1.3
                                                                              $950145
      DO 155 J = 1.3
                                                                               5250146
      \Delta I(I,J) = AL(I,J)/ATT
                                                                              5751147
  155 CONTINUE
      FEI = 1./AL(1.1)
                                                                               $350148
                                                                               $250149
      FU1 =-FE1*AL(1,2)
                                                                              5050150
      FF2 = 1./AL(2.2)
      FG = 1./AL(3.3)
                                                                               $950151
                                                                              5050152
      FA1 = 0.
                                                                              SQ50153
      F42 = 0.
                                                                              5050154
      IF(AL(1,3).NE.O.) FA1=1./AL(1,3)
                                                                               5050155
       IF(AL(2,3).NE.J.) FA2=1./AL(2,3)
                                                                              SQ50156
      WRITE(6,5060)
                                                                              SQ50157
      WRITE(6.5070)
      WRITE (6.5080)(A(I.1),A(I.2),A(I.3),B(I.1),B(I.2),B(I.3),D(I.1),
                                                                               5950158
                                                                               5050159
     1 D(I,2),D(I,3), I = 1,3)
                                                                               SQ50160
      WR ITE(6,5090)
      WR ITF(6,5100)
                                                                              $950161
                                                                               $75 1162
      WRITF (6.5110)(AUT(J.1), AOT(J.2), ANT(J.3), AL(J.1), AL(J.2),
                                                                               5750163
      1 \text{ AL}(J_1,3), J = 1,3
                                                                              5050164
      WRITE (6.5120)
      WRITE (6.5130) FEL. FE2. FUL. FG
                                                                               5950165
                                                                              $950166
      IF (KEYL.GT.O) CALL BEND
                                                                              5250167
      IF (KEY1.GT.O) SO TO 10
                                                                              $950168
      IF (KFY2.EQ.O) GO TO 160
```

```
5050169
     DO 156 L = 1.NLC
     READ (5.1025) N(L.1), N(L.2), N(L.3), M(L.1), M(L.2), M(L.3), T(L)SQ50170
                                                                            SQ50171
 156 CONTINUE
     IF (KEY4.EQ.0) GU TO 158
                                                                            5950172
     CALL TEMP
                                                                            SQ50173
                                                                            SQ50174
 158 CONTINUE
                                                                            5050175
     WR ITE(6, 1070)
     DO 157 L = 1.NLC
                                                                            5050176
                                                                            SQ50177
     WRITE(6.1080) L
     WRITE(6,1090) N(L,1), M(L,1), N(L,2), M(L,2), N(L,3), M(L,3), T(L)SQ50178
                                                                            5050179
 157 CONTINUE
                                                                            5057180
     CALL BEND
                                                                            $950181
 160 IF (KEY3.EQ.O) GO TO 180
     IF (KEY3.EQ.2) GO TO 170
                                                                            SQ50182
                                                                            SQ50183
     READ (5.1020) SIG1, SIG2, SIG3, PH1
                                                                            5050184
     WRITE (6,1040) SIG1, SIG2, SIG3, PHL
 170 CALL STEC
                                                                            5050185
     CALL SSRC
                                                                            $950186
                                                                            SQ50187
     IF (KEY3.EQ.1) GO TO 180
                                                                            $050188
     CALL SURFS
 180 CUNTINUE
                                                                            SQ50189
     IF (KEY5.EQ.0) GO TO 10
                                                                            $950190
     READ (5,1020) ( QX(I), QY(I), I = 1, NLC )
                                                                            SQ 50 19 1
                                                                            5050192
     WR [TF(6,5140)
                                                                            $050193
     WRITF(6,5150) ( [, QX(I), QY(I), I = 1,NLC)
                                                                            5050194
     CALL SHEAR
     G3 TO 10
                                                                            SQ50195
                                                                            SQ 50 196
1000 FORMAT (56H
                                                                            SQ50197
                                                                            SQ 50198
   1
                                                                            5050199
1010 FORMAT (815)
                                                                            SQ 50 20 0
1020 FORMAT (6F10.0)
                                                                            SQ 50 20 1
1025 FURMAT (7FS.U)
                                                                            SQ 50 20 2
1030 FORMAT (215.2F10.0)
1040 FORMAT (1H1.5x. *** INPUT AVERAGE STRESSES **** // 5X+ * SIGMA-1 = * + SQ 50 20 3
    1 F10.2.5X. *SIGMA-2 = *, F10.2.5X, *TAUXY = *, F10.2.5X, *ANGLE TO STRESQ50204
    2SS STATE = '.F10.5 / )
                                                                            SQ50205
1050 FORMAT(///.* *** ALLOWABLE STRAIN DATA ****//IX, MATYPE*, 3X,
                                                                            SQ50206
                                                                            SQ50207
    1 *LIMIT STRAIN*,7X,
    2 LIMIT STRAIN . 7X . LIMIT STRAIN . 7X . LIMIT STRAIN . 7X . LIMIT STRAIS 57208
    34.7x.*LIMIT STRAIN*/10x.*1 - DIRECTION*.6x.*2 - DIRECTION*.9x.
                                                                            SQ 50 20 9
    4*SHEAR*,11x,*1 - DIRECTION*,6x,*2 - DIRECTION*,9x,*SHEAR*/11x,
                                                                            $950210
    5*COMPPESSION*.8X.*COMPRESSION*.8X.*CNEGATIVE*,12X.*POSITIVE*,11X,
                                                                            $950211
    6*POSITIVE*,11X,*POSITIVE*// )
                                                                            $950212
                                                                            SQ50213
1060 FORMAT (1X.13.8X.F7.4.12X.F7.4.11X.F7.4.13X.F7.4.12X.F7.4.12X.
                                                                            SQ 50 21 4
    1 F7.4 / )
1070 FORMAT(1H1.10X. *** INPUT DATA FOR COMBINED N - M ANALYSIS ****//)SQ50215
1080 FORMATIOX. LOAD CASE NUMBER 1,12 / )
                                                                            SQ 50216
1090 FORMAT( 5X,*NX = ',F10.0,10X, MX = ',F10.0 //
                                                                            SQ50217
    1
              5x.*NY = *.F10.0.10x.*MY = *.F10.0 //
                                                                            SQ 50 21 8
              5X,^{NXY} = ^{1},^{1}0.0,^{1}0X,^{MXY} = ^{1},^{1}0.0 ////
                                                                            SQ50219
                                                                            SQ 50 22 0
              5x. TEMPERATURE = 1, F10.0 /////// )
5000 FORMAT (////15X, * *** INPUT DATA *** ///
                                                                            5050221
    1 5x, 'KEY1 = ', 15 // 5x, 'KEY2 = ', 15 // 5x, 'KEY3 = ', 15 //
                                                                            SQ 50 22 2
    2 5x * 'KEY4 = ' * 15 // 5x * 'KEY5 = ' * 15 //
                                                                            SQ 50 22 3
    3 5x. THE NUMBER OF LAYERS IN THE LAMINATE IS 1.12 //
                                                                            $950224
```

```
4 5X. THE NUMBER OF MATERIAL TYPES IS 1.12 //
                                                                           $050225
    5 5X. THE NUMBER OF LOADING CONDITIONS IS 1,12 // )
                                                                           SQ 50 22 6
5020 FORMAT (1HC, **** MATERIAL DATA **** // )
                                                                            $050227
5030 FIRMAT ( 5X. MATYPE', 5X. F1', 14X. F2', 14X. U1', 15X. G', 15X. ALPHAS050228
    11* 10X + A J PHA 2* , 10X + A L PHA 6* // ( 6X , I3 , 1X , F15 , 7 , 1X , E15 , 7 , 1x ,
                                                                            $350229
    2 E15.7. 1x,E15.7. 1x,E15.7, 1x,E15.7, 1x,E15.7
                                                                           S 151230
5040 FORMAT(1H1.**** LAYER DATA ****//10X.*LAYER NO.
                                                          MATYPE*,7X,*ORIES050231
    INTATION . 11X. THICKNESS / )
                                                                           $450232
5050 FORMAT (5X.2110.2F20.5)
                                                                           $050233
5060 FORMAT (1H1,///15x,**** OUTPUT DATA ****////10x,*COMPOSITE PROPERTS050234
    1 IES*/// 1
                                                                           5050235
5070 FORMAT (IH .15x. "A MATRIX", 35x. "B MATRIX", 35x, "D MATRIX"// )
                                                                           $050236
5080 FURMAT (1H +E12.5+2X+12.5+2X+112.5+5X+E12.5+2X+112.5+2X+112.5+5X+SQ50237
    1E12.5.2X.E12.5.2X.[12.5/ ]
                                                                           $050238
5090 FORMAT (///)
                                                                           $050239
5100 FORMAT (1H +15x, *(A/T) MATRIX*, 25x, *(A/T) INVERSE MATRIX*///)
                                                                           $050240
5110 FORMAT (1H +E12.5+2X+F12.5+2X+E12.5+5X+E12.5+2X+F12.5+2X+F12.5 /)
                                                                           5050241
5120 FORMAT (1H .///: 5x. AVERAGE LAMINATE ELASTIC CONSTANTS 1// )
                                                                           SQ50242
5130 FORMAT(1H .*EX = *.E12.5.2x.*EY = *.E12.5.2x.*UX = *.E12.5.2x.*GXY = *SQ50243
    1.E12.5 //// )
                                                                           5050244
5140 FORMAT (1H1,1UX, **** SHEAR FORCES **** /// 5X, *LOAD CASE*, 6X,
                                                                           SQ 50 245
    1 '0X', 8X, 'QY' // )
                                                                           SQ 50 24 6
5150 FORMAT ( 8X.12.4X.F10.0.F10.0 )
                                                                           SQ50247
                                                                           $050248
     END
                                                                           5050249
```

```
SUBPOUTINE STEC
                                                                             5950250
      COMMON AL(3.3), CALF1(400), CALE2(400), CALE3(400), TALE1(400),
                                                                             SQ57251
     1 TALE2(40C), TALE3(400), ACT(3,3), TH(400), Q11(400), Q12(400),
                                                                             SU50252
                                                                             5057 153
     2 922(400), Q66(400), BLF(18), A(3,3), B(3,3), D(3,3), AH(401),
                                                                             5057254
     3 AT(400), E1(400), E2(400), U1(400), U2(400), G(400), SB1(18),
     4 QBAR(400,3,3), GAM(3,400,3), 514(400), S2A(400), S3A(400),
                                                                             SQ 50 25 5
     5 SJ(1200), S(50), X(50), Y(50), XN(50), YN(50), FX(3), FY(3),
                                                                             SQ53256
     6 SIGX(1200), SIGY(1200), MATYPE(400)
                                                                             SQ50257
      COMMON BSTAR(3.3), CSTAR(3.3), DSTAR(3.3), DSTARI(3.3), BDC(3.3), SQ57258
     1 APRIME(3,3), BPRIME(3,3), CPRIME(3,3), DPRIME(3,3), ASTAR(3,3),
                                                                             SQ 57259
     2 BAB(3.3). Z(401), AI(3.3), EO(10.3), E(17.401.3), K(10.3),
                                                                             $050250
     3 N(10.3). M(10.3). NT(10.3). MT(10.3). QQ11(400). QQ22(400).
                                                                             SQ 50 26 1
                                                                             SQ5)262
     4 0012(400), 0366(400), ALPHAC(400), TAL(3,400), TGA(3,400),
     5 ALPHA1(400), ALPHA2(400), ALPHA6(400), T(10), QX(10), QY(10)
                                                                             $050263
      COMMON CU. CO2. SI. SI2. KEY1, KEY2. KEY3. KEY4. KEY5. SICO. SIGI.SQ50264
     1 SIG2, SIG3, PH1, CON, I, J, I2, I4, MA, NN, DAF, II, LDR, KK,
                                                                             5051265
     2 16. NLC. DAF3. DAF6. ATT, L. MLI. MB. DFL
                                                                             5057266
                                                                             SQ50267
      REAL K. N. M. NT. MT
C
                                                                             SQ 50268
C
      ROTATE THE AVERAGE STRESSES TO THE REFERENCE AXIS
                                                                             SQ50269
C.
                                                                             $950270
      IF(KFY3.NE.1) GO TO 10
                                                                             SQ50271
      CON = PH1 * C.0174533
                                                                             5050272
                                                                             SQ50273
      CO = COS(CON)
      CD2 = CD**2
                                                                             5057274
                                                                             SQ 50 275
      SI = SIN(CON)
                                                                             $252276
      SI2 = SI**2
      SICC = SI*CO
                                                                             S050277
      CIGI = SIG1*CJ2 + SIG2*SI2 - 2.*SIG3*SICO
                                                                             5050278
      CIG2 = SIG1*SI2 + SIG2*CO2 + 2.*SIG3*SICO
                                                                             SQ50279
      CIG3 = SIG1*SIC() - SIG2*SICO + SIG3*(CO2-SI2)
                                                                             $050280
C.
                                                                             $950281
C
      COMPUTE THE LAMINATE STRAINS
                                                                             SQ50282
                                                                             $050283
                                                                             SQ50284
   10 MX = 1
                                                                             5050285
      [F(KEY3.EJ.2)MX=6
                                                                             505)286
      DO 20 I=1.MX
      114 = 3×1 - 2
                                                                             $250287
                                                                             $957288
      IF(KFY3.EQ.1) GO TO 30
                                                                             3250289
      M7 = 1
                                                                             $250290
      IF(I.GE.4) MZ = I-3
      CIGI = 0.
                                                                             5050291
                                                                             5050292
      rig2 = 0.
      CIG3 = 0.
                                                                             5050293
                                                                             5250294
       IF(I.GE.4) GO TO 40
                                                                             5050295
      GO TO (12,14,16), MZ
   12 \text{ CIG1} = 1.0
                                                                             5050296
      GD TO 30
                                                                             5050297
   14 \text{ CIG2} = 1.0
                                                                             SQ 50 29 8
      GO TO 30
                                                                             5050299
   16 \text{ CIG3} = 1.0
                                                                             $350300
      GO TO 30
                                                                             SQ50301
                                                                             $050302
   40 GD TO (42,44,46), MZ
   42 \text{ CIG1} = -1.0
                                                                             SQ 50303
                                                                             5057304
      GO TO 30
                                                                             $150305
   44 \text{ CIG2} = -1.0
```

	GO TO 30		5057306
46	CIG3 = -1.0		5.051307
30	BLF(NA) =	AL(1.1)*CIG1+AL(1.2)*CIG2+AL(1.3)*CIG3	50 50 30 8
	BLF(NA+1) =	AL(2+1)*CIG1+AL(2+2)*CIG2+AL(2+3)*CIG3	5052309
	BLF(NA+2) =	AL(3.1)*CIG1+AL(3.2)*CIG2+AL(3.3)*CIG3	\$050310
20	CONTINUE		5350311
	RETUPN	•	SQ 50 31 2
	END		\$050313

```
SUBROUTINE SSRC
                                                                             5050314
      COMMON AL(3.3), CALE1(400), CALE2(400), CALE3(400), TALE1(400),
                                                                             5050315
     1 TALE2(400), TALE3(400), AOT(3.3), TH(400), Q11(400), Q12(400),
                                                                             SQ50316
                                                                             5050317
     2 022(400), Q66(400), BLF(18), A(3,3), B(3,3), D(3,3), AH(401),
                                                                             5050318
     3 AT(400), E1(400), E2(400), U1(400), U2(400), G(400), SB1(18),
                                                                             5951314
     4 QBAR(400.3.3). UAN(3.400.3). $14(400). $24(400). $34(400).
     5 SJ(1200) + S(5)) + X(50) + Y(50) + XN(50) + YN(50) + FX(3) + FY(3) +
                                                                             $350320
     6 SIGX(1200), SIGY(1200), MATYPE(400)
                                                                             SJ57321
      COMMON BSTAR(3.1), CSTAP(3.3), DSTAR(3.3), DSTARI(3.3), BDC(3.3),
                                                                            5051322
     1 APPIME(3.3), RPRIME(3.3), CPRIME(3.3), DPRIME(3.3), ASTAR(3.3),
                                                                             $050323
                                                                             $250324
     2 BAB(3.3). Z(401). ^1(3.3). E0(10.3). E(10.401.3). K(10.3).
     3 N(10.3), M(10.3), NT(10.3), MT(10.3), DOL1(400), DQ22(400),
                                                                             5250 325
     4 QQ12(400), QQ60(400), ALPHAC(400), TAL(3,400), TQA(3,400),
                                                                             5951326
     5 ALPHA1(400), ALPHA2(400), ALPHA5(400), T(10), QX(10), QY(10)
                                                                             SU50327
      COMMON CO. CO2. SI. SI2. KEY1. KEY2. KEY3. KEY4. KEY5. SICC. $161.5050328
     1 SIG2. SIG3. PHI. CIN. I. J. I2. I4. MA. NN. DAF. II. LDR. KK.
                                                                             505 1329
     2 I6, NLC. DAF3, DAF6, ATT, L. MLI, MR, DEL
                                                                             $950330
                                                                             SQ57331
      REAL K. N. M. NT. MT
                                                                             SQ50332
C
      SET INDEX
                                                                             5050333
                                                                             5050334
                                                                             $950335
      N1 = 1
                                                                             $950336
      IF(KEY3.EQ.2)N1=6
                                                                             5050337
      10000401 TTI 9W
                                                                             $050338
      00 80 Il=1.N1
      12 = 3 \times 11 - 2
                                                                             5051339
                                                                             SQ 50 34 0
C
r
      COMPUTE THE INPUT STRESS LEVEL
                                                                             5050341
                                                                             SQ 50 34 2
                 = 9LF(N2)*A:T(1,1)+BLF(N2+1)*AOT(1,2)+BLF(N2+2)*AOT(1,3)$Q50.343
      SB1(N2)
      SRI(N2+1) = HLF( 12)*AOT(2,1)+BLF(N2+1)*AOT(2,2)+BLF(N2+2)*AUT(2,3)SQ50344
      $B1(N2+2) = HLF(N2)*ANT(3,1)+BLF(N2+1)*ANT(3,2)+BLF(N2+2)*ANT(3,3)$Q50345
      WR ITF (6,50)
                                                                             5050346
                                                                             5057347
      WRITE(6,60) S31(N2), SB1(N2+1), S31(N2+2)
                                                                             5051348
      COMPUTE THE STRESSES AND STRAINS IN FACH LAYER
C.
                                                                             $050349
                                                                             5050 350
      WR ITE (6.10)
                                                                             5950351
                                                                             5057352
      PO 20 I2=1.MA
                                                                             5057353
      16 = MATYPE(12)
                                                                             5050354
      CDN = TH(12)*0.0174533
                                                                             5050355
      CO = COS(CON)
                                                                             SQ 50 356
      SI = SIN(CON)
                                                                             5050357
      CO2 = CO**2
                                                                             $050358
      S12 = S1**2
                                                                             5050359
      SICO = SI*CO
      FE1 = BLF(N2)#C 12+BLF(N2+1)#ST2+BLF(N2+2)#STCO
                                                                             SQ 50 36 0
                                                                             $950 361
      FE2 = BLF(N2)*SI2+BLF(N2+1)*CU?-BLF(N2+2)*SICO
      EE3 = -2.*8LF(N2)*SICO+2.*RLF(N2+1)*SICO+RLF(N2+2)*(CO2-SI2)
                                                                             SQ50362
                                                                             $450,363
      SS1 = \omega 11(12) * EE1 +
                                Q12(12) * FF2
                                                                             SQ 50 364
                                727(12) * 502
      552 = 012(12) * EE1
                                                                             50 57 36 5
      $$3 = 006(12) * EE3
      \Gamma U1 = TALE1(16)
                                                                             SQ 50 36 6
                                                                             5051367
      IF(FF1.LE.O.) EU1 = CAIF1(I6)
                                                                             SQ 50 36 8
      EU2 = TALE2(Io)
                                                                             5050369
       IF ( St 2 . L F . C . ) EU2 = ( Att 2(16)
```

```
EU3 = TALE3(16)
                                                                           5050370
   IF(EE3.LE.O.) EU3 = CALE3(16)
                                                                           SQ50371
   IF(KFY3-1) 30,30,40
                                                                           SQ50372
30 AMAR1 = 100.
                                                                           5050373
   IF(FEI.NE.C.) AMAR1 = CUI/EEI - 1.0
                                                                           SQ50374
   AMAR2 = 1CC.0
                                                                           SQ50375
   IF(EE2.NE.C.) AMAR2 = EU2/EE2 - 1.0
                                                                           SQ50376
   AMAR3 = 10C.0
                                                                           SQ50377
   IF(CE3.NE.O.) AMAR3 = CU3/EE3 - 1.0
                                                                           SQ50378
   WRITE(6,70)12,551,552,553,EE1,EE2,FE3,AMAR1,AMAR2,AMAR3
                                                                           5050379
   GO TO 20
                                                                           SQ50380
40 IF(EE1.EQ.C.) GO TO 41
                                                                           5050381
   SIA(12) = EU1/EE1
                                                                           SQ50382
   GD TO 42
                                                                           5950383
41 S1A(12)= 1000000.0
                                                                           $950384
42 IF(EE2.EQ.O.) GU TO 43
                                                                           SQ50385
   $2A(12)= EL2/EF2
                                                                           SQ50386
   GO TO 44
                                                                           5050387
43 S2A(12)= 1000000.0
                                                                           SQ 50 38 8
44 [F(EE3.E4.0.) GU TO 45
                                                                           SQ 50 389
   S3A(I2) = EU3 / EF3
                                                                           SQ59390
   GN TN 46
                                                                           SQ50391
45 \quad S3A(12) = 1000000.0
                                                                           5.050392
46 SD = 1.
                                                                           5050393
   IF(11.GE.4)SD=-1.
                                                                           SQ 50 394
   SD1=S1A(I2)*SJ
                                                                           $050395
   SD2=S2A(I2)*S)
                                                                           5050396
   SD3=S3A( [2]*SD
                                                                           SQ50397
   WRITF(6,70)12,SS1,SS2,SS3,EE1,EE2,EE3,SD1,SD2,SD3
                                                                           SQ57398
20 CONTINUE
                                                                           SQ50399
   IF (KEY3.NE.2) GO TO 80
                                                                           5050400
   DA = SIA(1)
                                                                           5050401
   CB = S2A(1)
                                                                           $950402
   C
      = S3A(1)
                                                                           5950403
   IF (MA . EQ. 1) GI) TO 95
                                                                           $950404
   DO 90 14=2,MA
                                                                          $250405
   IF(S1A(14).LE.DA) DA = S1A(14)
                                                                          $050406
   IF(S2A(I4).LF.Ud) DR = S2A(I4)
                                                                           5050407
   IF(S3A(I4).LE.DC) DC = S3A(I4)
                                                                           SQ50408
90 CONTINUE
                                                                           SQ50409
95 CONTINUE
                                                                           SQ5041 C
   DAF = DA
                                                                          SQ50411
   IF (DB.LE.CAF) DAF =DR
                                                                          $950412
   IF ( DC . LE . DAF) DAF =DC
                                                                          SQ50413
   WR ITF(6, 100) DAF
                                                                          SQ 50 41 4
   IF (II .EQ. 3) DAF3 = DAF
                                                                          $050415
   IF (II \cdot EQ \cdot 6) UAF6 = DAF
                                                                          SQ50416
80 CONTINUE
                                                                          5050417
   RETURN
                                                                           SJ 50 418
                                                                          5050419
10 FORMAT (2X, LAYER*, 5x, 'SIG-1', 3x, 'SIG-2', 7x, 'TAU-12', 8x, 'STR4[N-1'SQ50420
  1 +5X+ *STRAIN-2 * +5X+ *GAMMA-12 * +3X+ *ALLO - MAR-1 * +3X+ *ALLO - MAR-2 * +5Q50421
  2 3X. ALLU - MAR-12 // )
                                                                          $050422
50 FORMAT(////)
                                                                          SQ57423
60 FORMAT(1H .*
                  COMPOSITE AVERAGE STRESSES AT THE REFERENCE AXES*, SQ50424
  13X. 'SIGX = '.E12.5.5X. 'SIGY = ".E12.5.5X, 'SIGXY = '.E12.5 // )
```

```
70 FORMAT (3X.12.4X.E11.4.2X.E11.4.2X.E11.4.3X.E11.4.2X.E11.4.2X. SQ50426
1 E11.4.2X.E11.4.4X.F11.4.4X.E11.4 /) SQ50427
100 FORMAT (1H0.*ABSJLUTE VALUE OF THE MAXIMUM STPFSS = ',E12.4 ) SQ50428
6700 FORMAT (1H1)
C SQ50430
FND SQ50431
```

```
SQ 50 432
   SUBPOUTINE SURFS
   CIMMON AL(3,3), CALE1(400), CALE2(400), CALE3(400), TALE1(400),
                                                                          5050433
  1 TALF2(400), TALE3(400), AGT(3,3), TH(400), Q11(400), Q12(400),
                                                                          5050434
                                                                          5050435
  2 027(400), Q66(400), BLF(18), A(3,3), B(3,3), D(3,3), AH(401),
  3 AT(400), E1(400), E2(400), U1(400), U2(400), G(400), SRI(18),
                                                                          $950436
   4 QRAR(400,3.3), GAM(3,400,3), S14(400), S24(400), S34(400),
                                                                          5050437
  5 SJ(1200), S(50), X(50), Y(50), XN(50), YN(50), FX(3), FY(3),
                                                                          5050438
  6 SIGX(1200), SIGY(1200), MATYPE(490)
                                                                          5050439
   COMMON USTAR(3,3), CSTAR(3,3), DSTAR(3,3), DSTAR((3,3), BDC(3,3),
                                                                          $150440
   1 APFIME(3.3). BPRIME(3.3). CPRIME(3.3). DPRIME(3.3). ASTAR(3.3).
                                                                          SJ57441
   2 BAR(3,3), Z(401), 41(3,3), E0(10,3), E(10,401,3), K(10,3),
                                                                          50 50 44 2
   3 N(10.3), M(10.3), N((10.3), MT(10.3), OQ11(400), OQ22(400),
                                                                          5650443
   4 0012(400), 0066(400), ALPHAC(400), TAL(3,400), TOA(3,400),
                                                                          5453444
   5 ALPHA1(400), ALPHA2(400), ALPHA6(400), T(10), QX(10), QY(10)
                                                                          5050445
   COMMON CU. CO2. SI. SI2. KEY1. KEY2. KEY3. KEY4. KEY5. SICC. SIG1.SQ50446
   1 SIG2. SIG3. PHI. CON. I. J. I2. I4. MA. NN. DAF. II. LDR. KK.
                                                                          5050447
                                                                          $050448
   2 16, NLC. DAF3, DAF6, ATT, L. MLI, MR, DEL
                                                                          5050449
    REAL K. N. M. NT. MT
                                                                          5250450
    WR ITE (6. 10)
                                                                          SQ 50451
    LO 200 J=1.MA
                                                                          5050452
    BETA = TH(J) * 0.0174533
                                                                          5050453
    CO = COS(BETA)
                                                                          5057454
    SI = SIN(BETA)
                                                                          5150455
    CO2 = CO ** 2
    SI2 = SI ** 2
                                                                          5050456
                                                                          5050457
    CO * 12 = 0012
                                                                          50 5045 8
    00 \ 100 \ I = 1.3
                                                                          5050459
    GAM(1.J.1) = 3LF(N22)*C(12 + BLF(N22+1)*S12 + BLF(N22+2)*SICO
                                                                          $050460
    GAM(2+J+I) = BLF(N22)*SI2 + BLF(N22+1)*CO2 - BLF(N22+2)*SICO
                                                                          505 ) 46 1
    GAM(3.J.1) =-2.*BLF(N22)*SICO + 2.*BLF(N22+1)*SICO + BLF(N22+2) * SQ50462
                                                                          5050463
                  (CU2 - SI2)
   1
                                                                          5050464
100 CONTINUE
                                                                          $150465
200 CONTINUE
                                                                          5959466
    00.400 \text{ ITAU} = 1.2
                                                                          $950467
    IF (ITAU .EQ. 1) DAF = DAF3
                                                                          5050468
    IF (ITAU .EQ. 2) DAF = 0AF6
                                                                          5050469
    KAB = DAF * 0.01010 + 2.0
                                                                          5050470
    DD 340 KAA = 1.KAB
                                                                          5050471
    11 = 0
    WR 1TF16.3251
                                                                          5050472
    WR ITF (6.30)
                                                                          5050473
                                                                          5050474
    \Delta\Delta K = K\Delta\Delta - 1
                                                                          5057475
    TAUXY = AAK * 10000.0
    IFITAUXY.GE.DAF) TAUXY = 7AF*0.99
                                                                          SQ 50476
                                                                          $350477
    IF (ITAU.E4.2) TAUXY = -TAUXY
                                                                          SQ 50478
    DD 330 J=1.MA
                                                                          5257479
    16 = MATYPF(J)
                                                                          5252480
    FX(1) = TALF1(16)
                                                                          $250491
    FX(2) = TALE2(16)
                                                                          $950482
    FX(3) = TALE3(16)
    FY(1) = CALFI(16)
                                                                          $050483
                                                                          $959484
    FY(2) = CALF2(16)
                                                                          $95)485
    \Gamma Y(3) = CALE3(16)
                                                                          5050486
    '00 320 I=1.3
                                                                          5050487
    O(1) = TAUXY * GAM(I+J+3)
```

```
01 = FX(1) - 20
                                                                            50 50 48 8
     02 = FY(I) - 20
                                                                            5050489
     XIP = 0.1E15
                                                                            5250490
     XIN = 0.1E15
                                                                            5757491
     IF(GAM(I.J.1).EQ.0.) GO TO 210
                                                                            5050492
     XTP = Q1 / GAM(I+J+1)
                                                                            5252493
     XIN = 02 / GAM(I \cdot J \cdot I)
                                                                            5:257494
210 \text{ YIP} = 0.1E15
                                                                            505 1495
     YIN = 0.1E15
                                                                            5257496
     IF(GAM(I.J.2).EQ.0.) GD TO 220
                                                                            5050497
     YIP = Q1 / GAM(I,J,2)
                                                                            5050498
     YIN = Q2 / GAM(I.J.2)
                                                                            5750494
220 IBALL = - I
                                                                            5151500
     WRITE(6,230) J. XIP. YIP. TAUXY. I
                                                                            5050501
     APITE(6.230) J. XIN. YIN. TAUXY, TRALL
                                                                            5050502
     II = II + 2
                                                                            5050503
     SIGX(II-1) = XIP
                                                                            5050504
     SIGY(II-1) = YIP
                                                                            5050505
     SIGX(II) = XIV
                                                                            5250506
     SIGY(II) = YIV
                                                                            $350507
 320 CONTINUE
                                                                            $250508
     WR ITF(6. 325)
                                                                            5050509
 330 CONTINUE
                                                                            5357510
     CALL ISECT
                                                                            5050511
     WRITE(6.1000) TAUXY. (I. X(I), Y(I), I=1.KK)
                                                                            5050512
 340 CONTINUE
                                                                            5057513
 400 CONTINUE
                                                                            5050514
     RETURN
                                                                            5050515
                                                                            $950516
  10 FORMAT(////4X. TYTELD SURFACE COURDINATES!//)
                                                                            5750517
  3C FORMAT(3X. PLY NO.
                           SIGX INTERCEPT SIGY INTERCEPT
                                                                   TAUXY
                                                                            5057518
    1 MGDE*//)
                                                                            5050519
 230 FOPMAT(IH .3X, I 3, 6X, E12.5, 4X, E12.5, 4X, E12.5, 4X, T2)
                                                                            $95)520
 325 FORMAT(//)
                                                                            5050521
1000 FORMAT(1HC. THE INTERACTION YIELD COORDINATES!/ FOR TAUXY = 1,
                                                                            5757522
    1812.5. ARE! //! I
                                  X(I)
                                                  Y(1)*//(14.2015.5/))
                                                                            5057523
                                                                            5050524
     END
                                                                            5050525
```

```
SURPOUTINE ISECT
                                                                        SQ50526
                                                                        5053527
   GOMMON AL(3,3), CALF1(400), CALE2(400), CALE3(400), TALF1(400),
  1 TALE2(400), TALE3(400), ANT(3,3), TH(400), Q11(400), Q12(40)),
                                                                        5750521
  2 027(400), Q66(40C), BLF(18), A(3,3), B(3,3), D(3,3), AH(4C1),
                                                                        5050529
 3 AT(400), E1(400), F2(400), U1(400), U2(400), G(400), SB1(18),
                                                                        $950539
  4 OBAR(400.3.3), GAM(3.400.3), SIA(400), SZA(400), S3A(400),
                                                                        $250531
   SJ(1200), S(50), X(50), Y(50), XN(50), YN(50), FX(3), FY(3),
                                                                        5057532
 6 SIGX(1200), SIGY(1200), MATYPE(400)
                                                                        SQ50533
   COMMON BSTAR(3.3), CSTAR(3,3), DSTAR(3,3), DSTARI(3,3), BDC(3,3),
                                                                        5051534
    APRIME(3,3), BPRIME(3,3), CPRIME(3,3), DPRIME(3,3), ASTAR(3,3),
                                                                        $250535
   BAB(3.3), Z(401), AI(3.3), EO(10.3), E(10.401.3), K(10.3),
                                                                        5150536
   N(10.3), M(10.3), NT(10.3), MT(10.3), Q011(400), Q022(400),
                                                                        5154547
   J012(400), QJ66(400), ALPHAC(400), TAL(3,400), TQA(3,400),
                                                                        5050538
  5 ALPHA1(400), ALPHA2(400), ALPHA6(400), T(10), QX(10), QY(10)
                                                                        $250539
   COMMON CO. CO2. SI, SI2. KEY1. KEY2. KEY3. KEY4. KEY5. SICC. SIG1.5050540
  1 SIG2. SIG3. PH1. CIN. I. J. I2. I4. MA. NN. DAF. II. LDR. KK.
                                                                        $355541
  2 16. NLC. DAF3. JAF6. ATT, L. MLI. MB. DEL
                                                                        5050542
   REAL K. N. M. NT. MT
                                                                        5050543
   KK = 4
                                                                        5751544
   X(1) = 2000000.0
                                                                        5050545
                                                                        5950546
   X(2) = 0.0
                                                                        5050547
   X(3) = -2000000.0
   X(4) = 0.0
                                                                        5 3 5 3 4,4 4
   Y(1) = 0.0
                                                                        5 350 54 7
   Y(2) = 2000000.0
                                                                        5750550
   Y(3) = 0.0
                                                                        SQ50551
   Y(4) = -2300003.0
                                                                        5050552
   X(5) = 2000000.0
                                                                        5050553
                                                                        5450554
   Y(5) = 0.0
                                                                        5250555
   S(1) = -1.0
                                                                        5057556
   S(2) =
          1.C
                                                                        SQ50557
   S(3) = -1.0
                                                                        $252558
   S(4) =
           1.0
                                                                        SQ59559
   00 1000 J=1.II
   IF(ABS(SIGX(J)).GT.0.000100)G0 TO 15
                                                                        SQ50560
   WRITE(6,2100)
                                                                        $950561
   WR [TE(6, 3000)
                                                                        $959562
                                                                        5050563
   GO TO 600
15 SJ(J) = -SIGY(J)/SIGX(J)
                                                                        $9505 4
   ICOUNT = 0
                                                                        5050565
                                                                        5950566
   KCCUNT = 0
   NCOUNT = 0
                                                                        5350567
   DO 40 I=1.KK
                                                                        $150568
   IB = 0
                                                                        5 150569
   IP1 = I + 1
                                                                        5757570
   ZZ = SJ(J) - S(I)
                                                                        5050571
   Z1 = ABS(ZZ / S(I))
                                                                        SQ50572
   IF(71.LT.0.00010C)GJ TO 40
                                                                        5050573
   D1 = SJ(J)*(Y(I) - S(I) * X(I)) - SIGY(J)*S(I)
                                                                        5050574
   D2 = Y(1) - S(1) * X(1) - SIGY(J)
                                                                        5050575
   YY = D1 / ZZ
                                                                        $350576
   XX = D2 / ZZ
                                                                        5050577
     = AMAX1(X(I),X(IP1))
                                                                        5050578
   X2 = AMIN1(X(I),X(IP1))
                                                                        SQ50579
   Y1 = AMAX1(Y(I),Y(IPI))
                                                                        SJ57580
   Y2 = AMINI(Y(I),Y(IPI))
                                                                        $950581
```

```
IF(ABS(XX-X(I)).GT.10.0. OR.ABS(YY-Y(I)).GT.10.0) GO TO 18
                                                                             $050582
    IF(ICDUNT.EQ.O) NCOUNT = 1
                                                                             $050583
                                                                             SQ50584
    IF(ICOUNT.EO.1) KCOUNT = 1
    GO TO 25
                                                                             $050585
18 IF(ABS(XX-X(IP1)).GT.1C.O. OR.ABS(YY-Y([P1)).GT.1C.0)G7 TU 27
                                                                             $050586
    18 = 1
                                                                             5050587
    IF(ICOUNT.EQ.O) NCOUNT = 1
                                                                             $250588
                                                                             5050589
    IF(ICOUNT.EQ.1) KCOUNT = 1
    GO TO 25
                                                                             5050590
20 IF(XX.LT.X1.AND.XX.GT.X2) GO TO 25
                                                                             5057591
    GD TO 40
                                                                             5050592
25 IF(ICOUNT.EQ.1) GO TO 30
                                                                             SQ50593
    IF(IR.EQ.0) GU TU 27
                                                                             SQ 50 544
    IHAR1 = I+1
                                                                             5053595
    GO TO 29
                                                                             SQ51596
27 IBAR1 = I
                                                                             5051497
 29 XX1 = XX
                                                                             5050598
    YY1 = YY
                                                                             5050599
    ICOUNT = 1
                                                                             $0,50600
                                                                             SQ 50 60 1
    GD TO 40
                                                                             SQ50602
30 XAL = ABS(XX1-XX)
                                                                             5057603
    YAL = ABS(YY1-YY)
    ALTH2 = XAL**2 + YAL**2
                                                                             $950604
    IF(ALTH2.LT.625.0) KCOUNT = 0
                                                                             $251605
    IF(ALTH2.LT.625.0) GO TO 40
                                                                             SQ 50606
    IF(18.EQ.0) GO TO 35
                                                                             $959507
    IBAF2 = I+1
                                                                             S350608
    GO TO 36
                                                                             $0,50,609
 35 IBAP2 = 1
                                                                             $250610
 36 XX2 = XX
                                                                             $950611
    YY2 = YY
                                                                             $0,5061.2
    ICOUNT = 2
                                                                             5050613
                                                                             5050614
    GD TO 50
40 CONTINUE
                                                                             5050615
                                                                             $950616
    IF(ICOUNT.LT.2) GO TO 1000
                                                                             5050617
 50 \text{ JCOUNT} = 1
                                                                             5050618
    IF(SIGX(J)) 100,120,120
100 IF(SIGY(J)) 105.110.110
                                                                             $050419
105 NQUAD = 3
                                                                             $950620
    GO TO 150
                                                                             SQ 50 62 1
110 \text{ NQUAD} = 2
                                                                             $959622
    GO TO 150
                                                                             5057623
120 IF(SIGY(J)) 125,130,130
                                                                             $250624
                                                                             SQ 50 62 5
125 \text{ NQUAD} = 4
    GO TO 150
                                                                             $950626
130 \text{ NQUAD} = 1
                                                                             $050627
150 MCDUNT = 0
                                                                             50 50 62 8
                                                                             $950629
    KKK = KK + 1
                                                                             SQ 5063 0
    50 300 I = 1.KKK
    GO TO (200,280), JCOUNT
                                                                             $050631
                                                                             5050632
200 IF(1.LT.IBAR1) GJ TO 300
                                                                             5057633
    GD TO (210,220,230,240), NOUAD
                                                                             5.350634
210 [F(XX],LT,XX2.0R,YY1.GT,YY2] GD TO 260
                                                                             $250635
    GO TO 250
220 IF(XX1.LT.XX2.OR.YY1.LT.YY2) G3 T0 260
                                                                             5050636
    GO TO 250
                                                                             $950637
```

```
230 IF(XX1-GT-XX2-OR-YY1-LT-YY2) GO TO 260
                                                                             SQ 50 63 8
    GO TO 250
                                                                             5050639
240 IF(XX1.GT.XX2.DR.YY1.GT.YY2) GJ TO 260
                                                                             SQ 50 64 C
250 \text{ LCOUNT} = 1
                                                                             5057641
    GD TD 270
                                                                             $950442
260 LCOUNT = 2
                                                                             $050643
270 JCOUNT =
                                                                             SQ 50 64 4
    GD TO 300
                                                                             5750645
280 IF(I.GT.IBAR2) GO TO 300
                                                                             5050646
    MCDUNT = MCOUNT + 1
                                                                             $450647
300 CONTINUE
                                                                             5750548
    IF (LCOUNT . EQ. 1) MCOUNT = MCOUNT + NCOUNT
                                                                             $250649
    IF(LCOUNT.EQ.1) NODES = MCOUNT
                                                                             $950650
    IF(LCOUNT.EQ.2) MCOUNT = MCOUNT - KCOUNT
                                                                             5051651
    IF(LCOUNT.EQ.2) NODES = KK- MCOUNT
                                                                             SQ50652
    KNEW = KK + 2 + NODES
                                                                             $959653
    XN(1) = XX1
                                                                             SQ50654
    YN(1) = YY1
                                                                             SQ 50 65 5
    IF (LCOUNT.FU.1) GO TO 32 C
                                                                             5950656
    NO 310 I=1.MCJUNT
                                                                             $950657
    XN(I+1) = X(I3ARI + I)
                                                                             SQ50658
    YN(1+1) = Y(1BAR1 + 1)
                                                                             5050659
310 CONTINUE
                                                                             $250660
    XN(KNEW) = XX2
                                                                             $959661
    YN(KNEW) = YY2
                                                                             5050662
    GO TO 400
                                                                             $250663
320 \text{ XN}(2) = \text{XX}2
                                                                             $950664
    YN(2) = YY2
                                                                             $050665
    IX = KK - IBAR2
                                                                             5050666
    IF(IBAR2.EQ.KK)GU TO 340
                                                                             S050667
    DO 330 I=1.IX
                                                                             $950668
    N1 = I + 2
                                                                             $050669
    M1 = IHAR2 + I
                                                                             5050670
    XN(N1) = X(M1)
                                                                             SQ50671
    YN(N1) = Y(M1)
                                                                             SQ50672
330 CONTINUE
                                                                             SQ50673
340 NN = IX + 2
                                                                             SQ 50674
    UD 350 I=1.IBAR1
                                                                             $950675
    MM = NN + I
                                                                             5050676
    XV(MM) = X(I)
                                                                             S050677
    YN(MM) = Y(1)
                                                                             5950678
350 CONTINUE
                                                                             5052679
400 KK= KNEW
                                                                             5050680
    YN(KK+1) = YN(1)
                                                                             5050681
    XN(KK+1) = XN(1)
                                                                             5050682
    X(KK+1) = XN(1)
                                                                             SQ 50683
    Y(KK+1) = YN(1)
                                                                             $950684
    DO 410 I=1.KK
                                                                            $250685
                                                                             $950686
    X(I) = XN(I)
    Y(I) = YN(I)
                                                                             SQ50687
    DX = XN(I+1) - XN(I)
                                                                            $050688
    IF(ABS(DX).GT.0.C000001)GC TO 450
                                                                            SQ50689
    WRITE(6, 2020)
                                                                            5050690
    WR ITE (6.3000)
                                                                            5057691
    GO TO 600
                                                                             SQ 50692
450 DY = YN(I+I) - YN(I)
```

\$950693

```
IF(ABS(0Y).GT.0.C00001)G0 TO 5 30
                                                                           5050594
      WP ITF(6, 2110)
                                                                           $250695
      WR ITF(6.3000)
                                                                           $250696
      GD TO 600
                                                                           5157697
  500 S(I) = DY/DX
                                                                           5957698
  410 CONTINUE
                                                                           5050699
 1000 CONTINUE
                                                                           5050700
  600 RETURN
                                                                           505 ) 701
                                                                           5050702
 2100 FORMATILHO. COMPUTATIONS ARE STOPPED.
                                              A ZEPO IS DITHCTED FOR THE $050763
     *VALUE OF SIGX!)
 2020 FURMATCIHO. A LINE WITH A VERTICAL SLOPE IN THE INTERACTION PLCT WS. 5115
     IAS DETECTED. FURTHER COMPUTATIONS FOR THIS INTERACTION PLOT WERE $50.50706
     2TOPPED*///1
                                                                           5050707
 2110 FORMATCHO. CUMPUTATIONS ARE STOPPED.
                                               A SLOPE OF ZERE WAS DETECTESQ50708
     *D IN THE INTERACTION COPVE 1)
                                                                           5050709
 3000 FURMATCINO. THE FOLLOWING INTERACTION YIFLD CHORDINATES SHOW INTERSQ50710
                                                                         THSQ50711
     *MEDIATE VALUES DETERMINED*,/1x,*BEFORE DETECTING A ZERO VALUE.
     *ESE VALUES ARE TO BE USED FOR AN ERROR!/1x, ANALYSIS CHLY!/)
                                                                           5050712
C
                                                                           5050713
                                                                           5050714
      END
```

TARRESTERNATION OF THE PROPERTY OF THE PROPERT

```
SUBROUTINE BEND
                                                                            SQ50715
   COMMON AL(3.3). CALE1(400). CALE2(400). CALE3(400). TALE1(400).
                                                                            $050716
  1 TALE2(400). TALE3(400). ADT(3.3). TH(400). Q11(400). Q12(400).
                                                                            5050717
  2 922(400), 966(400), BLF(18), A(3,3), B(3,3), D(3,3), AH(401),
                                                                            SQ 50 718
  3 47(400), E1(400), E2(400), U1(400), U2(400), G(400), SR1(18),
                                                                            50 50 71 9
  4 QRAR(400.3.3). GAM(3.400.3). SLA(400). SZA(400). SBA(400).
                                                                            SQ 50720
  5 SJ(1200). S(50). X(50), Y(50), XN(50), YN(50), FX(3), FY(3),
                                                                            5050721
  6 SIGX(1200), SIGY(1200), MATYPE(400)
                                                                            $950722
   COMMON BSTAR(3.3). CSTAR(3.3). DSTAR(3.3). DSTAR((3.3). BDC(3.3). SQ50723
  1 APRIME(3.3). BPRIME(3.3). CPRIME(3.3). DPRIME(3.3). ASTAR(3.3).
                                                                            5057724
  2 BAB(3.3). Z(401). AI(3.3). E0(10.3). E(10.401.3). K(10.3).
                                                                            3050725
  3 N(10.3). M(10.3). NT(10.3). MT(10.3). QQ11(400), QQ22(400).
                                                                            SQ 57726
  4 9912(400), 9966(400), ALPHAC(400), TAL(3,400), TOA(3,400),
                                                                            5959727
  5 ALPHA1(400), ALPHA2(400), ALPHA6(400), T(10), QX(10), QY(10)
                                                                            5050728
   COMMON CO. CO2. SI. SIZ. KEYI. KEYZ. KEYZ. KEYA. KEYA. KEYA. SICO. SIGI.SQ50729
  1 SIG2. SIG3. PH1. CON. I. J. 12, 14, MA. NN. DAF. II. LDR. KK.
                                                                            SQ50730
  2 16. NLC. DAF3. DAF6. ATT, L. MLI. MR. DEL
                                                                            SQ 50731
   REAL K. N. M. NT. MT
                                                                            SQ 50 73 2
   00 10 1 = 1.3
                                                                            $950733
   00 \ 10 \ J = 1.3
                                                                            $950734
   0.0 = (L.1) PATZE
                                                                            $050735
   CSTAR(I.J) = 0.0
                                                                            5950736
   DSTAR(I.J) = 0.0
                                                                            $950737
   DSTARI(I.J)= 0.0
                                                                            SQ 50738
   BDC(1.J)
              = 0.0
                                                                            5050739
   BAH(I.J) = 0.0
                                                                            5050740
   APPIME(I.J) = 0.0
                                                                            5050741
   8PR [ME([.J)= 0.0
                                                                            S050742
   CPR [ME([.J)= 0.0
                                                                            SQ50743
   DPP IME( I. J) = 0.0
                                                                            5050744
   ASTAR(I,J) = 0.0
                                                                            5050745
10 CONTINUE
                                                                            SQ 50 74 6
   D0 30 I = 1.3
                                                                            5050747
   00 \ 30 \ J = 1.3
                                                                            SQ 50 74 8
   ASTAR(I,J) = AI(I,J)
                                                                            SQ50749
   00 20 L = 1.3
                                                                            SQ 30 75 0
   BSTAR(I,J) = BSTAR(I,J) + AI(I,L) + B(L,J)
                                                                            S050751
   CSTAR(I,J) = CSTAR(I,J) + B(I,L) + AI(L,J)
                                                                            SQ57752
20 CONTINUE
                                                                            SQ50753
30 CONTINUE
                                                                            $950754
   00 \ 50 \ 1 = 1.3
                                                                            SQ50755
   00.50 J = 1.3
                                                                            5950756
   00.40 L = 1.3
                                                                            SQ50757
   \mathsf{BAB}(I_{\bullet}J) = \mathsf{BAB}(I_{\bullet}J) + \mathsf{B}(I_{\bullet}L) + \mathsf{BSTAR}(L_{\bullet}J)
                                                                            5050758
40 CONTINUE
                                                                            SQ50759
50 CONTINUE
                                                                            5050760
   00 60 I = 1.3
                                                                           ·SQ50761
   00 60 J = 1.3
                                                                           5050762
   DSTAR(I.J) = D(I.J) - BAB(I.J)
                                                                           5050763
   BSTAR(I,J) = -BSTAR(I,J)
                                                                           5050764
60 CONTINUE
                                                                           5050765
   DET = (DSTAR(1,1)+DSTAR(2,2)+DSTAR(3,3))
                                                                           5950766
         (DSTAR(1.2) + DSTAR(2.3) + DSTAR(3.1))
                                                                           SQ50767
         (USTAR(1.3)+DSTAR(2.1)+DSTAR(3.2))
  2
                                                                           SQ50768
  3
       - (DSTAR(1.3)*DSTAR(2.2)*DSTAR(3.1))
                                                                           5050769
       - (DSTAR(1.1) + DSTAR(2.3) + DSTAR(3.2))
                                                                           $950770
```

```
- (DSTAR(1,2)*DSTAP(2,1)*DSTAR(3,3))
                                                                             SQ50771
   DSTARI(1.1) = (DSTAP(2.2)*DSTAR(3.3) - DSTAR(2.3)*DSTAP(3.2)) /DETSQ50772
   DSTARI(1.2) = (DSTAR(2.3)*DSTAR(3.1) - DSTAR(2.1)*DSTAR(3.3)) /DETSQ50773
   DSTARI(1.3) = (DSTAP(2.1)*DSTAR(3.2) - DSTAR(2.2)*DSTAR(3.1)) /DETSQ50774
   DSTARI(2.2) = (DSTAR(1.1)*DSTAR(3.3) - DSTAR(1.3)*DSTAR(3.1)) /DETSQ50775
   DSTARI(2.3) = (DSTAR(1.2)*DSTAR(3.1) - DSTAR(1.1)*DSTAR(3.2)) /DETSJ50776
    OSTARI(3.3) = (OSTAR(1.1) + DSTAR(2.2) - DSTAR(1.2) + DSTAR(2.1)) /DETSQ50777
                                                                             5050778
    DSTARI(2.1) = DSTARI(1.2)
                                                                             5050779
    DSTARI(3.1) = DSTARI(1.3)
                                                                             SQ 50 780
    DSTAPI(3.2) = DSTAPI(2.3)
                                                                             $250781
    00.80 I = 1.3
                                                                             5050782
    00.80 J = 1.3
                                                                             SQ 50 783
    DPRIME(I,J) = DSTARI(I,J)
                                                                             SQ 50 784
    00 \ 70 \ L = 1.3
    BPRIME(I,J) = BPRIME(I,J) + BSTAR(I,L)*DSTARI(L,J)
                                                                             SQ50785
    CPRIME(I,J) = CPRIMT(I,J) + DSTARI(I,L) *CSTAR(L,J)
                                                                             SQ 50 78 6
                                                                             SQ50787
70 CONTINUE
                                                                             $250788
80 CONTINUE
                                                                             SQ50,789
    00\ 100\ I = 1.3
                                                                             SQ50790
    D0 100 J = 1.3
                                                                             $950791
    CPR(ME(I+J) = -CPRIMF(I+J)
                                                                             SU51792
    00.90 L = 1.3
                                                                             5050793
    BDC(I+J) = BDC(I+J) + BPRIME(I+L)*CSTAR(L+J)
                                                                             5050794
90 CONTINUE
                                                                             SQ 50 795
100 CONTINUE
                                                                             SQ 50 796
    00 \ 110 \ I = 1.3
                                                                             5250797
    00.110 J = 1.3
                                                                             SQ 50 79 8
    \Delta PRIME(I,J) = ASTAR(I,J) - BOC(I,J)
                                                                             $250799
110 CONTINUE
                                                                             $0,50,800
    WRITE (6,900)
                                                                             $050901
    WRITE (6.1000)
    WRITE (6.1010) (APRIME(1.1), APRIME(1.2), APRIME(1.3), BPRIME(1.1)SQ50802
   1 . BPRIME(1,2), BPRIME(1,3) , I = 1,3)
                                                                             S050a03
                                                                             SQ 50 80 4
    WRITE (6.1030)
    WRITE (6.1010) (CPRIME(1.1), CPRIME(1.2), CPRIME(1.3), DPRIME(1.1)SQ57805
                                                                             SQ50406
   1 . OPRIME(1,2). DPRIME(1,3) . I = 1,3)
                                                                             SQ57307
    WRITE(6,1060)
                                                                             SQ50808
    WR ITE (6.1020)
                                                                             5050309
    IF (KEY1.EC.1) GU TO 200
                                                                             SQ 50810
    UN 135 L = 1.NLC
                                                                             SQ50811
    00 \ 130 \ I = 1.3
                                                                             SQ 5.)812
    FO(1,1) = 0.0
                                                                             SQ 50813
    K(L.I) = 0.0
                                                                             SQ 50 81 4
    DD 120 J = 1.3
    FO(L \cdot I) = EO(L \cdot I) + APRIME(I \cdot J) * N(L \cdot J) + BPRIME(I \cdot J) * M(L \cdot J)
                                                                             5050815
                                                                             $950316
    K(L \cdot I) = K(L \cdot I) + CPRIME(I \cdot J) *N(L \cdot J) + DPRIME(I \cdot J) *M(L \cdot J)
                                                                             5050817
120 CONTINUE
                                                                             5250818
130 CONTINUE
                                                                             S750819
135 CONTINUE
                                                                             SQ 50 82 0
    WRITE (6.1080)
    WRITE (6.1090)
                                                                             SQ50821
                                                                             SQ 50822
    00 136 L = 1.NLC
                                                                             5050823
    WRITF (6.1100) L
    WRITE (6.1110) EO(L.1), K(L.1), EO(L.2), K(L.2), EO(L.3), K(L.3)
                                                                             $050324
                                                                             $950325
136 CONTINUE
                                                                             SQ 50826
    CO 155 L = 1.NLC
```

```
ML1 = 1
                                                                           SQ50883
     GN TN 186
                                                                           SQ 50884
 190 CONTINUE
                                                                           $450885
 195 CONTINUE
                                                                           $9.50 886
 200 CONTINUE
                                                                           SQ50887
     RETURN
                                                                           SQ50888
                                                                           $25,1989
 900 FORMAT (1H1.10X. **** BENDING OUTPUT DATA ****//// }
                                                                           SQ57490
1000 FORMAT (27X, "A-PRIME MATRIX", 40X, "B-PRIME MATRIX" // )
                                                                           5050991
1010 FORMAT (10X.E14.7.3X.E14.7.3X.E14.7.6X.E14.7.3X.E14.7.3X.E14.7.7)
                                                                          $252892
1020 FORMAT (27X+*C-PRIME MATRIX*,40X+*D-PRIME MATRIX* ///// )
                                                                           5050893
1030 FORMAT (//)
                                                                           5050894
1040 FORMAT (3X,12,4X,E11,4,2X,F11,4,2X,E11,4,3X,F11,4,2X,F11,4,2X,
                                                                          5050895
    1 E11.4.2X.E11.4.4X.F11.4.4X.E11.4 / )
                                                                           SQ50496
1050 FORMAT(1H1.* *** COMBINED BENDING AND MEMBRANE STRESSES. STRAINS. S050897
    1AND MARGINS OF SAFETY FOR EACH LAYER *****///2X,*LAYER*,5X,*SIG+1*,SQ50398
    2 8x+*51G-2*+7x+*TAU-12*+8x+*STRAIN-1*+5 x+*STRAIN-2*+5x+*GAMMA-12*+SQ50499
    3 6X. MAR-1 10 10 X. MAR-2 1.10 X. MAR-12
                                                                           $257900
1060 FORMAT ( / )
                                                                           SQ50 701
1070 FORMAT (10X. LOAD CASE NUMBER 1.12 / )
                                                                           $050902
1080 FORMAT ( //// )
                                                                           $950903
1090 FORMAT (10x,**** MID-PLANE STRAINS AND CURVATURES ****/// )
                                                                           5950904
1100 FORMAT (5X. LOAD CASE NUMBER = 1. 12 // )
                                                                           SQ57905
1110 FORMAT (5x, ^{6}E) - x = ^{6}E15.7, 10x, ^{6}K - x
                                                                          SQ57906
                                                  *,E15.7 //
                          = ',E15.7,10X,'K - Y
                                                 = ',E15.7 //
             5X. 10 - Y
                                                                          $950907
             5X.*E0 - XY = *.E15.7.10X.*K - XY = *.E15.7 /
                                                                          5050908
5000 FORMAT (1CX+"Z = "+F10.6+5X+"THETA = "+F5.0 )
                                                                           SQ 50 90 9
                                                                          $950910
     END
                                                                           5050911
```

```
5057912
     SURPOUTINE TEMP
     COMMON AL(3.3). CALF1(400). CALE2(400). CALE3(400). TALE1(400).
                                                                            $050713
    1 TALF2(400). TALE3(400). ADT(3,3), TH(400), Q11(400), Q12(400).
                                                                            5050914
    2 Q22(400). Q66(400). BLF(18). A(3.3). B(3.3). D(3.3). AH(401).
                                                                            5050915
    3 AT(400). E1(400). F2(400). U1(400). U2(400). G(400). SB1(18).
                                                                            5050916
    4 OBAR (400.3.3). GAM(3.400.3). SIA(400). SZA(400). S3A(400).
                                                                            SQ50917
      SJ(1200). S(50). X(50). Y(50). XN(50). YN(50). FX(3). FY(3).
                                                                            5050918
                                                                            5050919
      SIGX(1200). SIGY(1200). MATYPE(400)
     COMMON BSTAR(3.3). CSTAR(3.3). DSTAR(3.3). DSTARI(3.3). BDC(3.3).
                                                                            5050920
    1 APPIME(3.3). BPRIME(3.3), CPRIME(3.3), DPRIME(3.3), ASTAR(3.3),
                                                                            SQ50921
      BAB(3.3) . Z(401) . AI(3.3) . FO(10.3) . F(10.401.3) . K(10.3) .
                                                                            5050722
    3 N(10.3). M(10.3). NT(10.3). MT(10.3). QQ11(400). QQ22(400).
                                                                            5050423
    4 0012(400). 0266(400). ALPHAC(400). TAL(3,400), TOA(3,400).
                                                                            5050924
      ALPHA1(400), ALPHA2(400), ALPHA6(400), T(10), QX(10), QY(10)
                                                                            $050925
      COMMON CO. CO2. SI. SIZ. KEYI. KEYZ. KEY3. KEY4. KEY5. SICC. SIGI. SQ50926
     1 SIG2. SIG3. PHI. CON. I. J. IZ. I4. MA. NN. DAF. II. LDR. KK.
                                                                            5950927
                                                                            5050928
     2 16. NLC. CAF3. DAF6. ATT. L. MLI. MB. DEL
                                                                            SQ 50 929
      REAL K. N. M. NT. MT
                                                                            5050930
                                                                            5050931
      COMPUTE THE TEMPERATURE INDUCED N AND M VECTORS
C
                                                                            $950932
C
                                                                            $950933
           5 L = 1. VLC
      ממ
                                                                            $950934
           4 I = 1.3
      nn
                                                                            5050935
      NT(L.1) = 0.0
                                                                            5050936
      MT(L.I) = 0.0
                                                                            SQ50937
    4 CONTINUE
                                                                            5050938
    5 CONTINUE
                                                                            $ 250939
      CO 10 1 = 1.MA
                                                                             5050940
      Q011(1) = C.0
                                                                             5050941
      9922(1) = 0.0
                                                                             SQ50942
      0012(1) = 0.0
                                                                            5050943
      0066(1) = 0.0
                                                                            $050944
       ALPHAC(I) = 0.0
                                                                             5050945
   10 CONTINUE
                                                                             5050946
       on 30 I = 1.3
                                                                             5050747
       00 \ 20 \ J = 1.00
                                                                             5050948
       U = (L \cdot I)AQT
                                                                             5050749
   20 CONTINUE
                                                                             5050950
    30 CONTINUE
                                                                             5050951
       DO 50 L = 1.NLC
                                                                             5050952
       99 40 I = 1.MA
                                                                             SQ 50 95 3
       IM = MATYPE(1)
                                                                             5050954
       U2(IM) = E2(IM) / E1(IM) * U1(IM)
                                                                             SQ 50 95 5
       DEL = i \cdot 0 - U1(IM)*U2(IM)
                                                                             5050956
       3011(I) = E1(IM) / DEL
                                                                             5052957
       0022(1) = E2(1M) / DEL
                                                                             5950958
       2J12(I) = 2Q11(I)*U2(IM)
                                                                             5050959
       4066(I) = G(IM)
                                                                             5050960
 c.
                                                                             $950961
       COMPUTE QQ * ALPHA
                                                                             5450962
       DALP11 = QQ11(1)*ALPHA1(IM) + QQ12(I)*ALPHAZ(IM)
                                                                             5050963
       QALP22 = QQ12(1)*ALPHA1(IM) + D022(1)*ALPHA2(IM)
                                                                             SQ 50 76 4
                                                                             5050965
       UALP66 = QG66(I) *ALPH46(IM)
                                                                             5050966
            = TH(I)*0.0174533
       CON
                                                                             SQ50967
             = CUS(CON)
       CO
```

```
SQ 50 96 8
      002 = 00**2
                                                                             S050969
           = SIN(CON)
      SI
      SI2 = SI**2
                                                                             $950970
                                                                             5050471
      SICO = SI + CO
                                                                             5250972
ſ.
      TRANSFURM (QQ * ALPHA) INTO X - Y SYSTEM
                                                                             5050973
C
                                                                             5050974
      TOA(1.1) = QALP11 * CO2
                                                 - 2.0 + OALP66 + SICU
                                + QALP22 + SI2
                                                                             5051975
                                + QALP22 * CO2 + 2.0 * QALP66 * SICO
      TQA(2.1) = QALP11 * S12
                                                                             $050976
      TQA(3.1) = QALP11 + SICO - QALP22 + SICO + QALP66 + (CO2 - SI2)
                                                                             5050977
C
                                                                             S050978
   40 CONTINUE
                                                                             SQ 50 979
   50 CONTINUE
                                                                             SQ57980
                                                                             5057981
      COMBINE THE LAMINA
                                                                             5050982
C
                                                                             5050983
      DO 80 L = 1.NLC
                                                                             5050984
                                                                             $0,50,485
      109 \ 70 \ I = 1.3
      DO 60 J = 1.MA
                                                                             5050986
               = NT(L+I) + TO\Delta(I+J) + \{AH(J+I) - AH(J\}\}
                                                                             5050987
      NT(L.I)
               = MT(L,1) + TQA(I,J) * (AH(J+1)**2 - AH(J)**2)
                                                                             5051988
      MT(L.I)
   GO CONTINUE
                                                                             5050089
   70 CONTINUE
                                                                             5050990
                                                                             5050791
   80 CONTINUE
                                                                             5057992
      L = 1
      00 86 I = 1.3
                                                                             5050993
      00.85 J = 1.3
                                                                             5050 194
                                                                             5050995
      ALPHAC(I) = ALPHAC(I) + AI(I+J)*NT(L+J)
   85 CONTINUE
                                                                             5250996
   86 CONTINUE
                                                                             5050997
      DO 100 L = 1.NLC
                                                                             $252998
          90 I = 1.3
                                                                             $250999
      MT(L+I) = 0.5*MT(L+I)
                                                                             5051000
   90 CONTINUE
                                                                             5951901
  100 CONTINUE
                                                                             $251002
      WP ITE (6, 1000)
                                                                             5051003
      WRITE (6+1010) (ALPHAC(I), I = 1+3)
                                                                             5051 104
      00 \ 105 \ L = 1.NLC
                                                                             5951005
      WRITE (6.1020) NT(L.1), NT(L.2), NT(L.3), MT(L.1), MT(L.2),
                                                                             $051006
     1 MT(L,3)
                                                                             5051007
  105 CONTINUE
                                                                             5.751008
      DO 120 L = 1.NLC
                                                                             5251009
      00 110 I = 1.3
                                                                             5051010
                  T(L) * NT(L,I) + N(L,I)
                                                                             5251011
      N(1 . I)
              =
                                                                             5051012
      M(L+1)
                 T(L) * MT(L+I) + M(L+I)
              =
                                                                             5051013
  110 CONTINUE
  120 CONTINUE
                                                                             5351014
      PETURN
                                                                             5051015
                                                                             5051016
 1000 FORMAT (1H1.10X.***** THERMAL EXPANSION DATA ****//// )
                                                                             5051017
 1010 FORMAT (5X. THEP MAL EXPANSION COEFFICIENT X FOR COMPOSITE = 1.
                                                                             SQ 51 01 8
     1F15.7//5X. THERMAL EXPANSION COEFFICIENT Y FOR COMPOSITE = 1.
                                                                             5051019
     2915.7//5x, *THERMAL EXPANSION COEFFICIENT XY FOR COMPOSITE = **
                                                                             $051020
     3415.7///)
                                                                             $351021
 1020 FORMAT ( 5X. COEFFICIENT OF THERMAL FORCE
                                                    NX = 1,E15.7//
                                                                             $951022
                5X. COEFFICIENT OF THERMAL FORCE
                                                    NY = 1,515.7//
                                                                             5051023
     1
```

```
2 5X.*COLFFICIENT OF THERMAL FORCE NXY = *,E15.7// S051024
3 5X.*COLFFICIENT OF THERMAL MOMENT MX = *,E15.7// S051025
4 5X.*COLFFICIENT OF THERMAL MOMENT MY = *,E15.7// S051026
5 5X.*COLFFICIENT OF THERMAL MOMENT MXY = *,E15.7/// S051027
C END S051029
```

```
SUBPOUTINE SHEAR
                                                                        S051030
   COMMON AL(3.3), CALE1(400), CALE2(400), CALE3(400), TALE1(400),
                                                                        SQ51031
  1 TALE2(400), TALE3(400), ANT(3,3), TH(400), 011(400), 212(400),
                                                                        5951932
  2 972(400), 966(400), RLF(18), 4(3,3), B(3,3), D(3,3), AH(401),
                                                                        5051033
  3 AT(400), E1(400), F2(400), U1(400), U2(400), G(400), SR1(18),
                                                                        5051034
  4 ORAP(400.3.3). GAM(3.400.3), SIA(400), SZA(400), S3A(400),
                                                                        5051035
    SJ(1200), S(50), X(50), Y(50), XN(50), YN(50), FX(3), FY(3),
                                                                        $951 136
  6 SIGX(1200), SIGY(1200), MATYPE(400)
                                                                        5051037
   CUMMON BSTAR(3.3). CSTAR(3.3). DSTAP(3.3). DSTAR((3.3). BDC(3.3).
                                                                        5051038
  1 APRIME(3,3), BPRIME(3,3), CPRIME(3,3), DPRIME(3,3), ASTAR(3,3),
                                                                        5051039
    BAB(3+3) + Z(401) + A1(3+3) + E0(10+3) + E(10+401+3) + K(10+3) +
                                                                        $951040
  3 N(10.3). M(10.3). NT(10.3). MT(10.3). QQ11(400). QQ22(400).
                                                                        $451041
  4 9912(400), 9366(409), ALPHAC(400), TAL(3,400), TOA(3,400),
                                                                        5351042
    ALPHA1(40C), ALPHA2(400), ALPHA6(400), T(10), QX(10), QY(10)
                                                                        5051743
   C14MON CO. CO2. SI. SI2. KEY1, KEY2, KEY3. KEY4. KEY5. SICO, SIG1, SQ51044
  1 SIG2. SIG3. PH1. CON. I. J. I2. I4. MA. NN. DAF. II. LDR. KK.
                                                                        SQ51045
    16. NLC. DAF3. DAF6. ATT, L. MLI. MB. DEL
                                                                        5951046
   PEAL K. N. M. NT. MT
                                                                        SJ 51 74 7
   MB = MA + 1
                                                                        $251.148
   CETO = D(1.1) * U(2.2) - D(1.3) * D(2.3)
                                                                        5051049
   WRITE (6.5000)
                                                                        5051050
   WRITE (6.5C10)
                                                                        $051051
   DO 70 L = 1.NLC
                                                                        5951052
                                                                        $351053
   COMPUTE THE THIRD DEPIVATIVES OF W -- W.R.T. X AND Y
                                                                        $951954
                                                                        $051055
   D3WX = - (D(2.2) / DETD)*QX(L) + (D(2.3) / DETD)*QY(L)
                                                                        5051756
   D3WY =
            ^1D(1.3) / D(TD)*QX(L) - (D(1.1) / DETD)*QY(L)
                                                                        5051057
   ML1 = 0
                                                                        5051058
   ML2 = 0
                                                                        5051059
   DD 60 I = 1.48
                                                                        $251060
   IF ( I . FQ. 1 ) GO TO 3
                                                                        5051061
   TF ( 1 .EQ. Ma) GO TO 3
                                                                        5051062
   GO TO 5
                                                                        5051063
 3 ZS = AH(I)
                                                                        5.751064
   J = [
                                                                        5051765
   SXZ = 0.0
                                                                        $251966
   SYZ = C.O
                                                                        5051067
   GO TO 50
                                                                        $951068
 5.7S = AH(I)
                                                                        $951.069
   IF (25 .LT. 0.0) GO TO 10
                                                                        $351070
      (75 .EQ. 0.0 .AND. ML1 .EQ. 0) GO TO 20
                                                                        SQ51071
   IF (75 .GT. 0.0 .AND. ML1 .EQ. 0) GO TO 30
                                                                        SQ51072
   J = 1
                                                                        5051073
   GO TO 40
                                                                        5051074
10 J = I - I
                                                                        5051075
   GO TO 40
                                                                        5051076
20 J = 1 - 1
                                                                        5051077
   ML1 = 1
                                                                        $251078
   GD TO 40
                                                                        5051079
30.75 = 0.0
                                                                        5951080
   J = I - 1
                                                                        $951081
   ML1 = 1
                                                                        5951982
40 CONTINUE
                                                                        $251083
           ( QBAR(J_*1_*1)*P3WX + Q3AR(J_*2_*3)*D3WY ) * (1.0 / 8.0) *
   SXZ =
                                                                        5051084
           (4.0*2S**2 - ATT**2)
                                                                        5051085
```

```
{ QBAR(J+1+3)+D3WX + QGAR(J+2+2)+D3WY } * (1+0 / 8+0) * ( 4+0+2S+2+2+ATT+2 }
                                                                              SQ51086
    1
                                                                              5051087
  50 WRITE (6.5030)
                        25. SXZ. SYZ
                                                                              $051088
     IF (ML2 .EQ. 1) GO TO 60
                                                                              $251084
     IF (75 .EQ. 0.0 .AND. ML1 .EQ.1 ) GO TO 55
                                                                              5951040
     60 TO 60
                                                                              5051221
  55 \text{ ML2} = 1
                                                                              5951092
     GO TO 5
                                                                              5051093
  60 CONTINUE
                                                                              5051 394
  70 CUNTINUE
                                                                              SQ51095
     RETUPN
                                                                              $251096
                                                                              5951097
5000 FORMAT (////10X+*** INTERLAMINAR SHEAR STRESSES **** //// )
                                                                              5051 UVR
5010 FORMAT (10x.*
                              Z
                                         TAU-XZ
                                                          TAU-Y71 /// 1
                                                                              5051099
5030 FORMAT (11x,2x,F11,5,6x,F7,0,8x,F7,0 // )
                                                                              5251100
                                                                              5951101
     END
                                                                              5051102
```

APPENDIX IV

SAMPLE PROBLEM INPUT

SAMPLE	PROBLEM	INTERA	CTIUN DIAGRA	AM	60/0 , 40/	45 DEGREES	121530P010001 121530P010002
ൗ ഗാറ്റാറ	. 2100000	-	ໍ້ ຮຽດກວນ.	0.0	0.0	0.0	1215300010003
1	1	O	0.30				121530P010004
2	ī	+45	0.20				121530P01c0J5
3	ī	-45	0.20				1215302010005
4	ī	0	J. 30				121530P010007
-0.00660	0 -0.006	460 -0.	01 0000 +0.00	05800	+0.002550	+0.913300	121530P010008
+100.0	0.0	0.0	0.6	0.0	0.0	0.0	121530P0100J9
+107.0	0.0		,				121530P010010

CC = 0010

APPENDIX V

SAMPLE PROBLEM OUTPUT

360 PROCEDURE SQ5 PRUBLEM 121530-01

PAGE 0001 01/12/70

SAMPLE PROBLEM INTERACTION DIAGRAM -- 60/0 , 40/45 DEGREES GENERAL DYNAMICS FORT WORTH DIVISION

*** INPUT CATA ***

KEY1 =

KEY? =

KEY3 =

KEY4 =

KEYS =

THE NUMBER OF LAYERS IN THE LAMINATE IS

THE NUMBER OF MATERIAL TYPES IS

THE NUMBER OF LOADING CONDITIONS IS

*** MATERIAL DATA ***

ALPHA2 0.0 ALPHA1 0.0 0.8500000E 06 0.2100000E 00 5 0.21 00000E 07 £2 0.20C0000E 08 E MATYPE

0.0

					LINIT STALI SHEAR POSITIVE	00100
					LIMIT STRAIN 2 - DIRECTION POSITIVE	0.0025
PAGE 0002 01/12/70					LIMIT STRAIN 1 - DIRECTION POSITIVE	0.0058
JRE 505 1530-01		THICKNESS	0.30000 0.20000 0.20000 0.30000		LIMIT STRAIN SHEAR NEGATIVE	-0.0100
360 PROCEDURE SQS PROBLEM 121533-01		ORIENTATION	0°0 48°00000 68°00000	:	LIMIT STRAIN 2 - DIRECTION COMPRESSION	-0.0067
		MA TYPE	m m m m	# DA TA *:	NON NON	
GENERAL DYNAWICS FORT WORTH DIVISION	*** LAYER DATA ***	LAYER NG.	m 0 m 4	*** ALLOWABLE STRAIN DATA ***	LIMIT STRAIN 1 - DIRECTION COMPRESSION	-0.0066
GENERAL FORT WOR	*** LAYE			*** ALL	MATVPE	1

GENERAL DYNAMICS FORT MOPTH DIVISION

360 PROCEDURE SQS PROBLEM 121530-01

PAGE 0

*** DUTPUT DATA ***

COMPOSITE PROPERTIES

D MATREX	-0.17983E 06 0.16026E 07 0.60810E 05 0.0 -0.17983E 06 0.60810E 05 0.19988E 06 0.0 0.0 0.0 0.0 0.94722E 05	·	0.0 0.0 0.37855E-04
B MATRIX		(A/T) INVERSE RATRÍK	
•	0.0 0.0 -0.17983E 06 -0.17983E 06	1 (1/4)	0.74466E-37 -0.42508E-07 -0.42508E-07 0.27971E-06 0.0
	0.0 0.0 0.26417E 07		0.0 0.0 0.26417E 07
A MATRIX	0.22347E C7 0.39147E 07 0.0	(A/T) MATRIX	0.22347E 07 0.39147E G7 0.0
	0.14705E 08 0.22347E G7 0.0		0.14705E C8 0.22347E G7 0.0

AVERAGE LAMINATE ELASTIC CONSTANTS

FX = 0.13429F 08 EY = 0.35751E 07 UX = 0.57085E 00 GXY = 0.26417E 07

GENERAL DYNAMICS FORT WORTH DIVISION 360 PRUCEDURE SQ5 PROBLEM 121530-01

PAGE 0004 01/12/70

*** INPUT DATA FOR COMBINED N - M ANALYSIS ***

LOAD CASE NUMBER 1

NX = 100. MX = C. NY = 0. MY = 0. MXY = 0.

TEMPERATURE = 0.

VANAM ICS	VISION
DVNAM	16:1
GENERAL DY	ACM L
SEN	FOR

360 PRCCEDURE 505 PROBLEM 121530-01

PAGE 0005 01/12/70

*** BENDING OLTPUT CATA ***

	A-PRIME MATRIX			B-PRIME MATRIX	
0.7484948E-07	-0.3965840E-07	-0.1196803E-14	-0.2372022E-13	0.6139651E-14	0.6681114
.0.396584UE-07	0.30086335-06	0.6341155E-15	0.1256796E-13	-0.3253044E-14	0.4959049
.0.1196303E-14	C.6341160E-15	0.40486G6E-06	0.31978916-07	0.3545241E-06	-0.1068273

D-PRIME NATRIX

*** MID-PLANE STRAINS AND CURVATURES ***

0.7484348E-05 F0 -

LOAD CASE NUMBER =

0.6139650E-12

-0.2372021E-11

E0 -

FO - XY

-0.3965339E-05

-0.11968C3E-12

× · ×

0.1256796E-13

-0.2372022E-13 0.6139651E-14 0.6681114E-C7

0.35452416-06

-0.3253044E-14

-0.1068273E-14

0.4959049E-06

C-PRIME MATRIX

0.31978916-07

9E-06

€E-07

3E-14

-0.2117280E-13

-0.1640532E-06

0.6338108E-06 -0.1640532E-06

0.5480290E-14

0.1162553E-04

C.5480290E-14

-0.2117280E-13

0.5371868E-05

C.6681114E-05

74

GENEPAL FORT MO	GENEPAL DYNAMICS FORT WORTH DIVISION		363 PROCEDURE SQS PROBLEM 121530-01	DURE 505 21530-01	PAGE 0006 01/12/70	0006 2/70			
03 ***	*** COMPINED BENDING AND MEMBRANE	AND MEMBRANE		STRAINS, AND M	STRESSES, STRAINS, AND MARGINS OF SAFETY FOR EACH LAVER ***	TY FOR EACH LI	IVER ***		
LAVER	1-915	516-2	TAU-12	STRAIN-1	STRAIN-2	GAMMA-12	HAR-1	MAR-2	MAR
	LOAD CASE NUMBER 1	1BE4 1							
-	Z = -0.5000C3 THETA 0.1486E 03 -0.5C51E 01	33 THETA -0.5C51E 01	= 0. -0.2839E 01	0.7485E-05	0.7485E-05 -0.3966E-05	-0.3341E-05	0.1139E 03	0.1678E 04	0.299
~	7 = -0.200000 THETA 0.2301E 02 0.56C5E 01		- 45. -0.9733E 01	3.1391E-05	0.2428E-05	-0.1145E-04	0.5313E 04	0.10496 04	0.872
 m	2 = 0.0 0.3613E 02	THE TA :	= 45. -0.9733E 01	0.1760E-05	0.1760E-05	-0.1145E-04	0.3295E 04	0.1448E 04	0.872
w	2 = 0.0 0.3613E 02	THE (A = 0.4492E 01	= -45. 0.9733E 01	0.1760E-05	0.176CE-05	0.1145E-04	0.3295E 04	0.1448E 04	0.872
4	2 = 0.200000 THETA 0.2301E 02 0.5605E 01	0.5605E 01	45. 0.9733£ 01	0.1391E-05	0.2428E-05	0.1145E-04	0.5313E 04	0.1049E 04	0.872
w	2 = 0.500000 THETA 0.1486E 03 -0.5C51E 01	00 THETA -0.5C51E 01	= 0. 0.2839E 01	0.7485E-05	0.7485E-05 -0.3966E-05	0.3341E-05	0.7739E 03	0.1678E 04	0.299

	ALLO - MAR-12	0.1000E 07	0.8549E 05	0.8549E 05	0.1000E 07			ALLO - MAR-12	0.1000E 07	0.3103E 05	0.3103E 05	0.1000E 07
SIGXY = 0.0	ALLO - MAR-2	0.1567E 06	0.1596E 06	0.1596E 06	0.1567E 06		SIGXY = 0.0	ALLO - MAK-2	0.9117E 04	0.2150E 05	0.2150E 05	0.9117E 04
SIGY = -0.59605E-07	ALLO - MAR-1	0.7789E 05	0.3630E 06	0.3630E 06	0.7789E 05		0.100006 01	ALLO - MAR-1	0.1553E 06	0.4890E 05	0.4830E 05	0.1553E 06
SIGY = -	GAMMA-12	0.0	-0.1170E-06	0.1170E-06	0.0		* 816Y *	GAMMA-12	0.0	0.3222E-06	-0.3222E-06	0.0
0.10000E 01	STRAIN-2	-0.4251E-07	0.1598E-07	0.1598E-07	-0.4251E-0		SIGX = -0.29802E-06	STRAIN-2	0.2797E-06	0.1186E-06	0.1186E-06	0.2797E-06
IXES SIGX =	STRAIN-1	D.7447E-07	0.1598E-07	0.15986-07	0.74476-07	90		STRAIN-1	-0.4251E-07	0.11866-06	0.11866-06	-0.42516-07
CUMPUSITE AVERAGE STRESSES AT THE REFERENCE AXES	TAU-12	0.0	-0.9943E-01	U.9943E-01	0.0	ESS = 0.7789E 05	COMPOSITE AVERAGE STRESSES AT THE REFERENCE AXES	TAU-12	0.0	0.2739E 06	-0.2739E 00	0.0
STRESSES AT	510-2	-0.5659E-01	J.4C?9E-01	0-4C79E-01	-0.5659E-01	MAXIMUM STR	STRESSES AT	SIG-2	0.57138 00	0.3028E 00	0.3C28E 00	0.5713E 00
SITE AVERAGE	1-918	10 377 5 01	0.3231E 00	0.3231E 00	0.1477E 01	ABSULUTE VALUE OF THE MAXIMUM STRESS =	SITE AVEPAGE	1-518	-0.7102E 90	0.2435E 01	0.2436E 01	-0.7302E 0J
Sudwind	£ A7£3	et	۰.	*	3	AB SULUTE	COMPD(LAVER	, ,	۲.	æ	4

\$16xY = 0.10000£ 01

0.0

SIGY

0.0

S16x =

0.9117E 04

ABSCLUTE VALUE OF THE MAXIMUM STRESS #

COMPOSITE AVERAGE STRESSES AT THE REFERENCE AXES

PAGE 0007 01/12/70

340 PROCEDURE SQS PROBLEM 121530-0.

GENERAL DYNAMICS FORT WENTH DIVISION

	ALLO - MAR-12	0.2642E 05	0.4432E 11	0.4432E 11	0.2642E 05			ALLO - MAR-12	-0.1000E 07.	-0.8549E 05	-0.8549E 05	-0.1000E 07			ALLO - MAR-12	-0.1000E 07	-0.3103E 05	-0.3103E 05
	ALLO - MAR-2	0.1000E 07	0.3519E 05	0.1347E 05	0.1000E 07		SLGXY = 0.0	ALLO - MAR-2	-0.5999E 05	-0.4168E 06	-0.4168E 06	-0.5999E 05		Sigxy = 0.0	ALLO - MAR-2	-0.2381E 05	-0.5615E 05	-0.5615E 05
	ALLG - MAR-1	0.1000E 07	0.3064£ 05	0.3487E 05	0.1000E 07		0.59605E-07	ALLO - MAR-1	-0.8863E 05	-0.4131E 06	-0.4131E 06	-0.8863E 05	V	-0.100006 01	ALLO - MAR-1	-0.1364E 06	-0.5565E 05	-0.5565E 05
0008 770	GAMMA-12	0.3785E-06	-0.2256E-12	-0.2256E-12	0.3785E-06		S167 =	GANNA-12	0.0	0.1170E-06	-0.1170E-06	0.0		- = A91S	GAMMA-12	0.0	-0.3222E-06	0.322E-06
PAUE 0008 01/12/70	STRAIN-2	0.0	-0.1893E-06	0.1893E-06	0.0		-0.10000E 01	STRAIN-2	0.4251E-07	-0.1598E-07	-0.1598E-07	0.4251E-07		0.29802E-06	STRAIN-2	-0.27976-06	-0.1186E-06	-0.1186E-06
EDURE 505 121530-01	STRAIN-1	0.0	0.18936-06	-0.1893E-06	0.0	E 05	AXES SIGK =	STRAIN-1	-0-7447E-07	-0.1598E-07	-0-1598E-07	-0.7447E-07	E 05	AXES SIGX =	TRAIN-1	0.4251E-07	-0.1186e-06	-3.1186E-06
360 PROCEDUR	TAU-12	0.3218E 00	-0.1918E-Ub	-0.1918f-U6	0.3218E CC	SS = 0.1347E	HE REFERENCE AXES	TAU-12	0.0	0.9943E-01	-0.9943E-01	0.0	SS = 0.5999E 05	THE REFERENCE AXES	TAU-12	0.0	-0.2739E 0G	0.2719€ 00
	S16-2	0.0	-0.3155E 00	0.31558 00	0.0	MAXIMLP STRESS	STRESSES AT THE REFERE	2-918	0.5669E-01	-0.4C79E-01	-0.46796-01	0.56696-01	ABSOLUTE VALUE OF THE MAXIMUM STRESS	STRESSES AT	S16-2	-0.5713E 00	-0.3028F UO	-0*36585 00
GENERAL DYNAMIGS FORT WERTH STVISION	\$16-1	3 •¢	0.37196 01	-0.3719E 01	٥ ٠ ٥	E VALUE OF THE	COMPOSITE AVERAGE	SI 6-1	-0.1477E 01	-0.3281E 00	-0.3281E 00	-0.1477E 01	E VALUE OF THE	COMPOSITE AVERAGE	SIG-1	0.7302E 00	-0.2476E 01	-7.2436F SI
GENERAL FORT WOR	LAVER	pre	2	m	4	ABSOLUTE VALUE)dhu3	LAYER	-	2	۳,	4	AB SOL UTE	JdwuJ	LAYER	F	7	m.

	-0.1000E 07		
	-0.2381E 05		
	-0.1304E 06		
PAGE 0009 01/12/70	0.4251E-07 -0.2797E-36 0.0		
360 PRUCEDURE 595 PRUSLEM 121530-01		0.23816 05	
GENERAL DYNAMICS FORT MORTH DIVISION	4 0.1302E CJ -0.5713E QC 0.5	ABSOLUTE VALUE OF THE MAXIMUM STRESS =	

000E 01	GAMMA-12 ALLO - MAR-1 ALLO - MAR-2 ALLO - MAR-12	-0.2642E 0\$	-0.4432E 11	-0.4432E 11	-0.2642E 05
SIGKY = -0.10000E OI	ALLO - MAR-2	-0.1000E 07	-0.1347E 05	-0-35196 05	-0.1000E 07
0.0	ALLO - MAR-1	-0.3785£-06 -0.1000E 07	0.2256E-12 -0.3487E 05	0.2256E-12 -0.3054E G5	-0.3785E-06 -0.1000E 07
0.0 × ¥518	GANNA-12	-0.3785E-06	0.2256E-12	0.2256E-12	-0.3785E-06
0.0	STRAIN-2	0•0	0.18936-06	0.18936-06 -0.18936-06	0.0
xES \$16X =	STRAIN-1	0.0	-0.1893E-06	0.18936-06	0.0
CUMPOSITE AVERAGE STRESSES AT THE RFFERENCE AXES SIGX = 0.0	140-12	-0.3219E 00	0.19186-06	0.1918E-U6	-0.321aE 00
STRE SSE S AT	2-918	o•c	0.31556 00	0.37195 01 -0.31556 00	0.0
DSITE AVERAGE	516-1	0.0	-0.3719E 0L	0.37199 01	0.0
3d MO 3	LAYEK	1	~	۳	4

YIELD SURFACE COCRDINATES

MODE	44444	-1-27
TAUXY	0000000 000000	2000 2000 2000
SIGY INTERCEPT	-0.13544F 06 0.15526F 06 0.91165E 94 -0.23410E 95 0.10009E 15	0.48304E 35 -0.25647E 05 0.21501E 05
SIGX INTERCEDT	0.77848F 05 -0.46632E 05 -0.59438E 05 0.10600E 15 0.10000E 15	0,362995 06 -2,413055 16 0,1535956
PI Y NG.		V () () (

0.1347E 05

48SOLUTE VALUE OF THE MAXIMUM STRESS =

GENEP FORT	AL DYNA WCRTH (MIC DIVI	S SION						EDURE \$95 121530-01	
	2 2		85489 85489			31 03 31 03			0.0 0.0	3 -3
	3 3 3 3 3 3	-0. 0. -0.	36299 41305 15959 41681 85489	E 06 E 06 E 06	-0. 0. -0.	4890 5564 2150 5615 3103 3103	9E 1F 5E 5E	05 05 05 05	0.0 0.0 0.0 0.0 0.0 0.0	1 -1 2 -2 -3
	4 4 4 4 4 4	-0. -0. 0.	77888 88632 59988 15668 10000	E 05 E 05 E 06	0. 0. -0. 0.	1364 1552 9116 2381 1000	6E 6E 0E 0E	06 04 05 15	0.0 0.0 0.0 0.0 0.0	1 -1 2 -2 -3 -3
	NTFRACT				RDINAT ARE	ES				
1	X ((1)			Y(I)					
1	-0.11	1055	06	-0.4	C687E	05				
2	0.34	23 OF	05	-0.1	86C8E	05				
3	0.75	901F	05	-0.3	4806E	04				
4	0.83	72 3E	05	0.1	C221E	05				
5	0.43	1965	25	7.1	5681E	05				
0	-0.91	35 2E	05	-0.4	7665F	04				
7	-0.11	180E	06	-0.4	C586E	05				
PLY	' N').	\$13	X INT	FRC CP	T SIG	Y IN	TE	RCEPT	TAUXY	MODE
	1		77834 48532	E 05		1364 1552			0.10000E 0.10000E	1 -1

GENERAL DYN FORT WORTH			360 P PROBL	ROCEDURE 505 EM 121530-01	
1 1 1	-C.59988E 0.15668E 0.10000E 0.10000E	05 06 15 15	0.91156E 04 -0.23810E 05 0.10900E 15 0.10900E 15	0.10000E 05 0.10000F 05 0.10000E 05 0.10000E 05	2 -2 3 -3
2 2 2 2 2 2	0.24453F -0.53151L 0.27804F -0.29835E -0.85489E 0.85489E	06 06 06 06 05 05	0.32945E 05 -0.71608F 05 0.77460E 05 -0.40196E 05 0.31035E 05 -0.31035E 05	0.10000F 05 0.10000E 05 0.10000E 05 0.10000E 05 0.10000E 05 0.10000E 05	1 -1 2 -2 -3 -3
3 3 3 3	C.48144E -0.29460E 0.41133E -0.53526E 0.85489E -0.85489E	06 06 05 06 05	0.64862E 05 -0.39690E 05 0.55417E 04 -0.72114E 05 -0.31035E 05 0.31035F 05	0.10000E 05 0.10000E 05 0.10000E 05 0.10000E 05 0.10000E 05	1 -1 2 -2 3 -3
4 4 4 4	0.77888E -0.89632E -0.59988E 0.15668E 0.10000E 0.10000E	05 05 05 06 15	-0.13644E 06 0.15526E 06 0.91166E 04 -0.23810F 05 0.10000F 15 0.10000E 15	0.10000E 05 0.10000E 05 0.10000E 05 0.10000E 05 0.10000E 05	1 -1 2 -2 -3 -3

THE INTERACTION YIELD CCORDINATES FOR TAUXY = 0.10000E 05 ARE

I	X(1)		Y(I)	
1	-0.553875	05	-0.3222PF	05
2	0.34230E	Q 5	-0.18608E	05
3	0.734836	05	-0.43584F	04
4	-0.12469E	05	0.72216E	04
5	-0.91352E	C 5	-0.47665E	04
6	-0.10334F	96	-0.25767E	05

PLY NO.	SIGX INTERCEPT	SIGY INTERCEPT	TAUXY	MODE
1	0.77836F 05	-7.13644E 06	0.13338E 05	1
1	-0.88632E 05	0.15526E 06	0.13338E 05	-1
1 1 1	-0.5998AE 05	U.91166F 04	0.13339£ U5	-2 -2 3
1	0.15668E 06	-0.23910E 05	0.13338E 05	-2
1	0.10000E 15	0.10000E 15	0.13338E 05	3
1	0.10000E 15	0.10000E 15	0.13338E 05	-3
,	0.204005.34	0 274195 05	A 13330F AF	•
2	0.20499E 06 -0.57105F 06	0.27618F 05 -0.76934E 05	0.13338F 05 0.13338E 05	1
2	0.31758E 06	-0.76934E 05 0.42786E 05	0.13338E 05 0.13338E 05	-1
•	-0.25881E 06	-0.34869E 05	0.13338E 05	-2
2	-0.85489E 05	0.31035F 05	0.13338F 05	-2 -2 3
2 2 2 2 2 2	0.85489E 05	-0.31035E 05	0.13338E 05	-3
3	0.52098F 06	0.70189F 05	0.13338E 05	1
7	-0.25506E 06	-0.34363E 05	0.13333E 05	-1
á	0.15959F 04	0.21501E 03	U.13338E 05	-2 -2 3
3	-0.57480F 06	-0.77441E 05	0.13338E 05	-2
3	7.85489E 05	-0.31035E 05	0.13338E 05	3
3	-0.85489E 05	0.31035F 05	0.13338F 05	-3
4	0.77888E 05	-0.13644E 06	0.13338E 05	1
4	-0.88632E 05	0.15526E 06	0.13338F 05	-1
4	-0.57488t 05	0.91166F U4	0.13338F 05	2
4	0.15668E 06	-0.23810E 05	0.133385 05	-2
4	0.10000F 15	0.10000E 15	0.13338E 05	3
4	0.10000b 15	0.10000F 15	0.133386 05	-2 -3 -3
				-

THE INTERACTION YIELD COOPDINATES FOR TAUXY = 0.13338F C5 ARE

I X(1) A(1)

1 -0.36908E 05 -0.29404E 05

GENERAL DYN FORT WORTH				CEDUKE SQ5 121530-01		PAGE 0013 01/12/70
2 0.34	230E 05 -	-0.184C8E	05			
3 0.62	782E 05 -	-0.82434E	04			
	C48E 05	0.43981F				
5 -0.91	352E C5 -	-0.47565E	04			
6 -0.10	C52E 06 -	-0.20821F	05			
PLY NO.	SIGX INTE	RCEPT SIG	Y INTERCEPT	TAUXY	MODE	
1	0.778886	05 -0	136445 06	-0.0	1	
1	-0.98632F	05 0.	15526E 06	-0.0	-1	
1 1	-C.59988E		91166E 04 23810E 05	-0.0 -0.0	2 -2	
1	0.10000E		10000E 15	-0.0	3	
1	0.10000E		10000E 15	-0.0	-3	
2	0.36279E	26 0.	48904E 05	-0.0	1	
2	-0.41305F		55649E 05	-0.0	-1	
2 2	0.15959F		21501F 05	-0.0	2	
2	-0.41681E -0.85489E		56155E 05 31035E 05	-0.0 -0.0	-2 3	
2	0.85489E		31035E 05	-0.0	-3	
					-	
_					_	
,3 3	0.36299E -0.41305E		48904E 05	-0.0	1 -1	
3	0.15959E		21501E 05	-0.0	2	
7	-0.41681E	0 6 -0.	56155E 05	-0.0	-2	
3	0.85489E		31035E 05	-0.0	3	
3	-0.85489E	05 0.	31035E 05	-0.0	- 3	

-0.13644E 06

0.15526E 06 0.91166E 04 -0.23810E 05 0.10000E 15 0.10000F 15 -0.0

-0.0

-0.0

1 -1 2 -2 3 -3

0.77888E 05 -0.88632E 05 -0.59988E 05 0.15668E 06 0.10000E 15

GENERAL DYNAMICS FORT WORTH DIVISION

360 PROCEDURE SQ5 PROBLEM 121530-01

PAGE 0014 01/12/70

THE	INTERACTION VIEL TAUXY = -0.0	D COURDINATES ARE
1	X(1)	Y(1)
1	-0.11105E 06	-0.40687E 05
?	0.34230E 05	-0.18608F 05
3	0.75901E 05	-0.34806E 04
4	0.83723E 05	0.10221E 05
5	0.43196E 05	0.15681E 05
6	-0.91352E 05	-0.4:665E 04
_		

-0.11180F 06

PLY NJ.	SIGX INTERCEPT	SIGY INTERCEPT	TAUXY	MUDE
1 1 1 1 1	0.77888E 05 -0.88632E 05 -0.59988E 05 0.15668E 06 0.13000E 15 0.10000E 15	-0.13644E 06 0.15526E 06 0.91166E 04 -0.23910E 05 0.10000E 15	-0.10000E 05 -0.10000E 05 -0.10000E 05 -0.10000E 05 -0.10000E 05	1 -1 2 -2 -3
2 2 2 2 2 2 2	0.48144E 06 -0.29460F 06 0.41133E 05 -0.53526E 06 -0.85489E 05 0.85489E 05	0.64962F 05 -0.39690E 05 0.55417F 04 -0.72114E 05 0.31035F 05 -0.31035E 05	-0.10000E 05 -0.10000E 05 -0.10000E 05 -0.10000E 05 -0.10000E 05	1 -1 2 -2 -3
3 3 3 3 3 3	0.24453E 06 -0.53151E 06 0.27804E 06 -0.29835E 06 0.85489E 05 -0.85489E 05	0.32945E 05 -0.71608E 05 0.37460E 05 -0.40196E 05 -0.31035E 05 0.31035E 05	-0.10000E 05 -0.10000E 05 -0.10000E 05 -0.10000E 05 -0.10000E 05 -0.10000E 05	1 -1 2 -2 3 -3

-0.4C586E 05

GENER	AL	DYN	AM	10	S
FORT	WOR	TH	DIV	ΙĨ	SLON

360 PROCEDURE SOS PROBLEM 121530-01

PAGE 0015 01/12/70

4	0.779886	05	-0.13644E	06	-0.100GGE	05	1
4	-0.88632E	05	0.15526E	06	-0.10000E	05	-1
4	-0.59988E	05	0.91166E	04	-0.10000E	U 5	2
4	0.15668F	06	-0.23810E	05	-0.10000E	05	-2
4	0.10000E	15	0.10000E	15	-0.100CDE	05	3
4	0.10000E	15	0.10000E	15	-0.10000F	05	-3

THE INTERACTION YIELD COORDINATES FOR TAUXY = -0.10000E 05 ARE

I	X(1)		(1)Y	
1	-0.55387E	05	-0.32228E	05
2	0.34230E	05	-0.186C8E	05
3	0.73483E	05	-0.43584E	04
4	-0.12469E	05	0.72216E	04
5	-0.913526	05	-0.47665E	04
6	-0.10334E	06	-0.25767E	05

PLY NJ.	SIGX INTER	CEPT	SIGY INTE	RCEPT	TAUXY		MODE
1	O.77888E	05	-0.13544E	06	-0.13338E	25	1
1	-0.88632F	05	0.155266	06	-0.13338E	05	-1
1	-0.59938E	05	0.91166F	04	-0.13338E	05	2
1	0.15668F	06	-0.23910E	05	-0.13338E	05	-2
1	0.10000E	15	0.10000E	15	-0.13338E	U 5	3
1	0.10000E	15	0.10000E	15	-0.13338E	05	-3
2	0 5300er	0.4	0.701805	05	0.10000	0.5	
2		06	0.701898		-0.13338E		1
2	-0.25506F	06	-0.34363£		-0.13338E		-1
2	0.15959E	04	0.21501E	03	-0.13338E	05	2
?	-0.57480E	06	-0.77441E	05	-0.13338E	05	-2
2	-0.85489E	0.5	0.31035E	05	-0.13338E	05	3
2	0.85489E	C 5	-0.31035E	05	-0.13338E		-3

GENERAL DYNAMICS FORT WORTH DIVISION		360 PROCEDURE \$95 PROBLEM 121530-01				
3 3 3 3 3	0.20499E -0.57105E		0.27618E		-0.13338E 05	1
3	0.317585	06	0.42786E		-0.13338E 05	-1 2
3	-0.25881F	0.6	-0.34869E		-0.13338E 05	-2
3		05	-0.31035E		-0.13338E 05	3
3	-0.85489E	05	0.31035E		-0.13338E 05	-3
4	0.77888E	05	-0.13644E	06	-0.13338E 05	1
4	-0.88632E	05	0.15526E		-0.13338E 05	-ī
4	-0.59988E	05	0.91166E	04	-0.13338E 05	Ž
4	0.15668E	06	-0.23810E	05	-0.13338E 05	-2
4	0.10000E	15	0.10000E	15	-0.13338E 05	3
4	0.10000E	15	0.10000E	15	-0.13338E 05	-3

PAGE 0016 01/12/70

THE INTERACTION YIELD COURDINATES FOR TAUXY = -0.13338E 05 ARE

I	X(I)X		Y(I)	
1	-0.36808E	05	-0.29404E	05
,	0.34230E	05	-0.186C8E	05
3	0.62782E	05	-0.92434E	04
4	-0.31048E	05	0.43981E	04
5	-0.91352E	05	-0.47665E	04
6	-0.10C52E	06	-0.2C821F	05

GENERAL DYNAMICS FORT WORTH DIVISION

360 PROCEDURE SQ5 PROBLEM 121530-01 PAGE 0017 01/12/70

*** SHEAR FORCES ***

LOAD CASE

OX

QY

1

100.

0.

*** INTERLAMINAR SHEAR STRESSES ***

TAU-YZ	TAU-XZ	2
u.	0.	-0.50000
0.	132.	-0.20000
35.	52.	0.0
-35.	52.	0.0
0.	132.	0.20000
0.	0.	0.50000

REFERENCES

- 1. J. E. Ashton, J. C. Halpin, and P. H. Petit, <u>Primer on Composite Materials: Analysis</u>, Technomic Publishing Co., Inc., Stamford, Connecticut, 1969.
- 2. S. W. Tsai, "Strength Characteristics of Composite Materials", NASA CR-224, April, 1965.
- 3. J. E. Ashton and J. M. Whitney, <u>Theory of Laminated Plates</u>, Technomic Publishing Co., Inc., Stamford, Connecticut, 1970.

